Calhoun: The NPS Institutional Archive

DSpace Repository

Theses and Dissertations | 1. Thesis and Dissertation Collection, all items

1974-12

Refinements of the seal subroutines and fan air flow maps for the XR-3 loads and motion program

Finley, Robert Alexander

Monterey, California. Naval Postgraduate School

http://hdl.handle.net/10945/17205

This publication is a work of the U.S. Government as defined in Title 17, United States Code, Section 101. Copyright protection is not available for this work in the United States.

Downloaded from NPS Archive: Calhoun

http://www.nps.edu/library

Calhoun is the Naval Postgraduate School's public access digital repository for research materials and institutional publications created by the NPS community. Calhoun is named for Professor of Mathematics Guy K. Calhoun, NPS's first appointed -- and published -- scholarly author.

Dudley Knox Library / Naval Postgraduate School
411 Dyer Road / 1 University Circle
Monterey, California USA 93943

REFINEMENTS OF THE SEAL SUBROUTINES AND FAN AIR FLOW MAPS FOR THE XR-3 LOADS AND MOTION PROGRAM

Robert Alexander Finley

DUDLEY KNOX LIBRARY
NAVAL POSTGRADUATE SCHOOL
MONTEREY, CALIFORNIA 93940

NAVAL POSTGRADUATE SCHOOL
Monterey, California

THESIS

REFINEMENTS OF THE SEAL SUBROUTINES
AND FAN AIR FLOW MAPS FOR THE
XR-3 LOADS AND MOTION PROGRAM

by

Robert Alexander Finley

December 1974

Thesis Advisor: A. Gerba Jr.

Approved for public release; distribution unlimited.

D164910

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) Refinements of the Seal Subroutines and Fan Air Flow Maps for the XR-3 Loads and Motion Program		5. TYPE OF REPORT & PERIOD COVERED Master's Thesis; December 1974 6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) Robert A. Finley		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS Naval Postgraduate School Monterey, California 93940		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS Naval Postgraduate School Monterey, California 93940		12. REPORT DATE December 1974 13. NUMBER OF PAGES 146
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office) Naval Postgraduate School Monterey, California 93940		15. SECURITY CLASS. (of this report) Unclassified 15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

XR-3
XR-3 Loads and Motion Computer Program
Fan Air Flow Maps
XR-2 Bow and Stern Seal Subroutines

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Refinements to the bow and stern seal subroutines of the XR-3 Loads and Motion computer program are made. New lift fan performance maps are developed and presented. Comparison studies of simulated performance of the original XR-3 model with the old and new fan maps are made under varying sea conditions. Measured roll and pitch transient behavior of the XR-3 test craft in calm water is compared with the

DD FORM 1 JAN 73 1473 (Page 1) EDITION OF 1 NOV 65 IS OBSOLETE S/N 0102-014-6601

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

(20. ABSTRACT Continued)

simulated response of both the original and the new model. In addition, simulated performances of the original and new models in irregular ahead seas are compared.

Refinements of the Seal Subroutines and Fan Air Flow Maps for the XR-3 Loads and Motion Program

by

Robert Alexander Finley
Lieutenant Commander, United States Navy
B.S., United States Naval Academy, 1965

Submitted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE IN ELECTRICAL ENGINEERING

from the

NAVAL POSTGRADUATE SCHOOL
December 1974

Thesis
F443
c. 1

DUDLEY KNOX LIBRARY
NAVAL POSTGRADUATE SCHOOL
MONTEREY, CALIFORNIA 93940

ABSTRACT

Refinements to the bow and stern seal subroutines of the XR-3 Loads and Motion computer program are made. New lift fan performance maps are developed and presented. Comparison studies of simulated performance of the original XR-3 model with the old and new fan maps are made under varying sea conditions. Measured roll and pitch transient behavior of the XR-3 test craft in calm water is compared with the simulated response of both the original and the new model. In addition, simulated performances of the original and new models in irregular ahead seas are compared.

TABLE OF CONTENTS

I. INTRODUCTION ---------- 11

A. BACKGROUND ---------- 11

B. OBJECTIVES ---------- 13

II. FAN PERFORMANCE MAP ANALYSIS AND COMPARISON ---- 14

A. INTRODUCTION ---------- 14

B. FAN MAP ANALYSIS AND DERIVATION ---------- 16

C. SIMULATED PERFORMANCE COMPARISONS BETWEEN ORIGINAL AND NEW FAN MAPS ---------- 24

III. SEAL MODEL REFINEMENTS ---------- 37

A. INTRODUCTION AND BASIC MODELING TECHNIQUE -- 37

B. BOW SEAL MODELING ---------- 49

C. STERN SEAL MODELING ---------- 59

IV. DATA ANALYSIS OF ACTUAL CRAFT TRANSIENT MOTION AND COMPUTER SIMULATION ---------- 67

A. INTRODUCTION ---------- 67

B. RUN DATA ANALYSIS ---------- 74

C. SIMULATION STUDIES OF THE TWO MODELS ------- 76

V. CONCLUSIONS AND RECOMMENDATIONS ---------- 109

APPENDIX A. Listing of BOWSEAL SUBROUTINE BOWSL ------- 115

APPENDIX B. Listing of Stern Seal Subroutine STNSL ---- 120

APPENDIX C. Listing of FAN subroutine FAN ---------- 124

APPENDIX D. Listing of Initial Conditions Subroutine INCON ---------- 127

BIBLIOGRAPHY ---------- 144

INITIAL DISTRIBUTION LIST ---------- 145

LIST OF TABLES

I. Sea State Wave Components ---------- 27

II. Simulated XR-3 Performance with Different Fan Maps ---------- 28

III. Calm Water Forced Oscillations Response ----- 77

LIST OF FIGURES

1. Performance and Fan Map Curves for the Joy Axivane Fan (Model AVR 87-55D2058) ---------- 18

2. Manufacturers' Specifications for the Joy Axivane Fan ---------- 19

3. Bow Seal and Plenum Chamber Fan Maps, Adjusted for Ducting Losses ---------- 22

4. Stern Seal Fan Map Adjusted to Account for Ducting Loss ---------- 23

5. Computer Simulation, Plenum Pressure versus Time, Speed 20 knots, Original Fan Maps, Sea State 1 ---------- 29

6. Computer Simulation, Pitch Angle versus Time, Speed 20 knots, Original Fan Maps, Sea State 1 ---------- 30

7. Computer Simulation, C.G. Draft versus Time, Speed 20 knots, Original Fan Maps, Sea State 1 ---------- 31

8. Computer Simulation, C.G. Acceleration versus Time, Speed 20 knots, Original Fan Maps, Sea State 1 ---------- 32

9. Computer Simulation, Plenum Pressure versus Time, Speed 20 knots, New Fan Maps, Sea State 1 ---------- 33

10. Computer Simulation, Pitch Angle versus Time, Speed 20 knots, New Fan Maps, Sea State 1 ------- 34

11. Computer Simulation, C.G. Draft versus Time, Speed 20 knots, New Fan Maps, Sea State 1 ------- 35

12. Computer Simulation, C.G. Acceleration versus Time, Speed 20 knots, New Fan Maps, Sea State 1 ---------- 36

13. Cross Sectional View of Pneumatic Seal as Installed in the XR-3 ---------- 40

14. Bow and Stern Seal Deflection Model (not to scale) ---------- 45

15. Seal Trailing Edge Height Above Keel versus Seal Wetted Length ---------- 47

16. Roll Motion versus Time, 20.429 knots ---------- 68

17. Pitch versus Time, 20.429 knots ---------- 69

18. Pitch Motion versus Time, 20.429 knots ---------- 70

19. Roll Transient versus Time, 11.79 knots -------- 78

20. Computer Simulation, Roll Angle versus Time, 11.79 knots, Original XR-3 ---------- 79

21. Computer Simulation, Roll Angle versus Time, 11.79 knots, New XR-3 ---------- 80

22. Pitch versus Time, 15.93 knots ---------- 81

23. Pitch Transient versus Time, 15.93 knots ------- 82

24. Roll Transient versus Time, 15.93 knots -------- 83

25. Computer Simulation, Pitch Angle versus Time, 15.93 knots, Original XR-3 ---------- 84

26. Computer Simulation Roll Angle versus Time, 15.93 knots, Original XR-3 ---------- 85

27. Computer Simulation, Pitch Angle versus Time, 15.93 knots, New XR-3 ---------- 86

28. Computer Simulation, Roll Angle versus Time, 15.93 knots, New XR-3 ---------- 87

29. Roll Transient versus Time, 19.45 knots -------- 88

30. Pitch versus Time, 19.45 knots ---------- 89

31. Pitch Transient versus Time, 19.45 knots ------- 90

32. Computer Simulation, Roll Angle versus Time, 19.45 knots, Original XR-3 ---------- 91

33. Computer Simulation, Pitch Angle versus Time, 19.45 knots, Original XR-3 ---------- 92

34. Computer Simulation, Roll Angle versus Time, 19.45 knots, New XR-3 ---------- 93

35. Computer Simulation, Pitch Angle versus Time, 19.45 knots, New XR-3 ---------- 94

36. Computer Simulation, 3 Degree Pitch Step Response, 19.45 knots, Original XR-3, Pitch versus Time ---------- 96

37. Computer Simulation, 3 Degree Pitch Step Response, 19.45 knots, Original XR-3, Plenum Pressure versus Time ---------- 97

38. Computer Simulation, 3 Degree Pitch Step Response, 19.45 knots, Original XR-3, Draft at C.G. versus Time ---------- 98

39. Computer Simulation, 3 Degree Pitch Step Response, 19.45 knots, New XR-3, Pitch versus Time ---------- 99

40. Computer Simulation, 3 Degree Pitch Step Response, 19.45 knots, New XR-3, Plenum Pressure versus Time ---------- 100

41. Computer Simulation, 3 Degree Pitch Step Response, 19.45 knots, New XR-3, Draft at C.G. versus Time ---------- 101

42. Computer Simulation, Plenum Pressure versus Time, 19.45 knots, New XR-3, Sea State 2 ------- 103

43. Computer Simulation, Plenum Pressure versus Time, 19.45 knots, Original XR-3, Sea State 2 -- 104

44. Computer Simulation, Draft at C.G. versus Time, 19.45 knots, New XR-3, Sea State 2 ---------- 105

45. Computer Simulation, Draft at C.G. versus Time, 19.45 knots, Original XR-3, Sea State 2 -------- 106

46. Computer Simulation, Pitch Angle versus Time, 19.45 knots, New XR-3, Sea State 2 ---------- 107

47. Computer Simulation, Pitch Angle versus Time, 19.45 knots, Original XR-3, Sea State 2 -------- 108

48. Bottom View of the XR-3 Showing Planing Areas at the Rear ---------- 111

ACKNOWLEDGEMENT

The author wishes to express his sincere appreciation to Associate Professor Alex Gerba Jr. without whose guidance and encouragement this period of study would not have been completed.

In addition the author wishes to thank Associate Professor Donald M. Layton and his technical assistant Mr. Michael O'Dell who spent many hours of their time collecting data used in this study.

And lastly the author would like to give a special measure of thanks to a close friend, Lcdr. G. T. Forbes, USN, who was of great assistance throughout this project.

I. INTRODUCTION

A. BACKGROUND

The speed limitation of the conventional displacement vessel has been recognized for many years. In an effort to effect a quantum increase in surface vessel speed the United States Navy has been developing various craft whose principal means of support is other than hydrostatic lift.

One type of craft currently receiving much attention is the surface effect ship or craft. In this category are the air cushion vehicles and captured air bubble craft (CAB). The general nature of these craft and their construction is well presented by Robert L. Trillo in Ref. 1. In these craft either all or a major portion of its support is derived from a pressure differential between the atmosphere and a plenum chamber which is open at the bottom. The speed advantages gained by this type of vessel are derived from two principal characteristics. It does not waste energy displacing a large volume of water and the frictional forces between the hull and water are greatly reduced by the craft riding on a cushion of air with only a minimum of the craft structure actually in contact with the water.

Vessels of this type are generally separated into two categories – "Air Cushion Vehicles" whose weight is entirely supported by the pressure differential in the plenum chamber and "Captured Air Bubble Craft" whose weight is partially

supported by sidewalls which extend into the water. It is the second type of vessel in which the United States Navy has become primarily interested for ocean going applications.

The term Captured Air Bubble (CAB) is possibly a misnomer since in this type of craft the air does leak out and has to be continually replenished by supply fans. The leakage though is relatively slow when it is compared to the air cushion vehicle which has continuous air gap around the periphery of the craft and hence the fans that replenish the air in the plenum chamber have to be larger and more powerful than those of a CAB of similar size.

This thesis is concerned with one aspect of the development of the Captured Air Bubble vehicle and that is the simulation of such craft utilizing a digital computer, specifically the Loads and Motion Program developed by Oceanics, Inc.

The basic rigid body analysis and spatial relationships of the Loads and Motion program are well documented in Ref. 2. Also covered are the principal dynamic and static approximations used in developing the equations of motion for the craft in its six degrees of freedom.

A copy of this program was delivered to the Naval Postgraduate School in October of 1972 which had been specifically tailored for the Bell (100B) 100 ton craft. Leo and Boncal in Ref. 3 succeeded in converting this program to represent the XR-3 test craft.

B. OBJECTIVE

The purpose of this thesis was to take a second more detailed look into all of the aspects of seal modeling and the fan performance map with the idea of possibly making improvements in these representations before testing the computer model of the XR-3 under dynamic conditions.

II. FAN PERFORMANCE MAP ANALYSIS AND COMPARISON

A. INTRODUCTION

As the surface effect ship is predominately dependent on the plenum lifting force for its performance, the characteristics of the lifting fans are important if valid studies of the craft in question are to be made.

Leo and Boncal reported in Ref. 3 that the steady state operating conditions of the XR-3 were obtained by increasing the leakage area of the craft until the proper equilibrium pressure was maintained in the main plenum. This area was twenty-six square feet. As the cross-sectional area of the plenum is less than twenty square feet this leakage area was out of proportion to properly represent the leakage area of the XR-3.

While operating above hump speed the XR-3 test craft has been observed to have a gap underneath the sternseal of from four to five inches. Slight leakage does occur at the bowseal as reported by Ref. 3 but the total leakage area is estimated to be not over four square feet.

To appreciate the effect this leakage area has on computed craft performance an understanding is required of the method by which the pressure is calculated in the plenum.

When the program is executed an estimation of the initial operating conditions must be supplied by the user. Besides velocity and thrust, initial conditions for plenum pressure, displacement and pitch angle must be supplied. From the

displacement, pitch angle and velocity for calm water conditions, a plenum volume is computed. Using the leakage areas supplied, exit flow rates are computed for the bow and stern seals. The fan subroutine is then called using the pressure in the plenum, bow and stern seals as primary arguments. Using these pressures supply flow rates are established for the fans that supply air to the plenum, and both seals. As the seals discharge into the main plenum the sum of these fan flow rates establish the total influx rate. The net flow being the difference between the influx and efflux rates establishes the new plenum pressure for the next calculation interval based upon the adiabatic perfect gas law. This new pressure creates a new plenum lifting force which is then balanced by the defining differential equations of motion resulting in a new operating condition of craft attitude and displacement.

In studying craft motion in calm water the leakage area is of little or no consequence since no additional leakage areas are normally developed beneath the sidewalls or seals, and the rate of change of plenum volume is relatively slow. On the other hand, when the program is executed in simulated sea states where gap areas are generated beneath the seals and sidewalls and plenum volume does change quite rapidly the leakage areas and fan maps become of prime importance.

It must be emphasized though that it is not the leakage area itself that affects craft performance. It is rather the relative size of the fixed leakage area with respect to

the variable leakage areas generated around the periphery of the craft by wave motion and craft attitude and position which is important.

B. FAN MAP ANALYSIS AND DERIVATION

Isolation of the factors which caused the large discrepancy between observed steady state gap area and calculated area required an examination of both the efflux and influx equations for possible errors.

The equation used to establish leakage flow rates under the seals and the sidewalls are the same. This equation is given below

$$\dot{Q} = C_f A_L (2\Delta p/\rho)^{1/2}$$

It is the general flow equation for a sharp edged orifice in turbulent flow conditions. As the orifice coefficient, C_f, is the only variable in the equation that could be dependent on craft geometry and its range was limited between unity and six tenths; the efflux equations were eliminated as the source of the error. The only area left for possible error was the fan maps themselves.

The fan maps in question are arrays which give fan flow rates in cubic feet per second as a function of plenum or seal pressure. They are entered as data in "INCON" as characteristics of the specific craft being modeled.

It was found that the fan maps constructed by Leo and Boncal to represent the fans installed in the XR-3 were based upon incorrect information. Actual fan performance data for the fans currently installed is presented[1] in Figure 1, and physical characteristics in Figure 2.

The fan performance map given by the manufacturer, Joy Manufacturing Company, is based upon flow that is not impeded by air ducts. It is therefore optimistic for any system that contains long ducts as these ducts will modify considerably the fan performance by creating ducting losses.

The best way to obtain the actual fan performance maps in a duct system would be to actually measure the flow rates as the pressure in the receiving reservoir (in this case the plenum) is varied. As this method was impractical in the case of the XR-3 another method of estimating the modified fan performance had to be devised.

The method outlined below was utilized and although it probably does not give exact results the fan maps thus achieved should adequately represent the actual fan performance of the XR-3.

---

[1]The fan data was provided by Associate Professor of Aerology D.M. Layton who is in charge of the actual XR-3 test program at the Naval Postgraduate School. He has verified that the fans installed are Joy Model AVR87-55D2058 for which the data given in Figures 1 and 2 are correct.

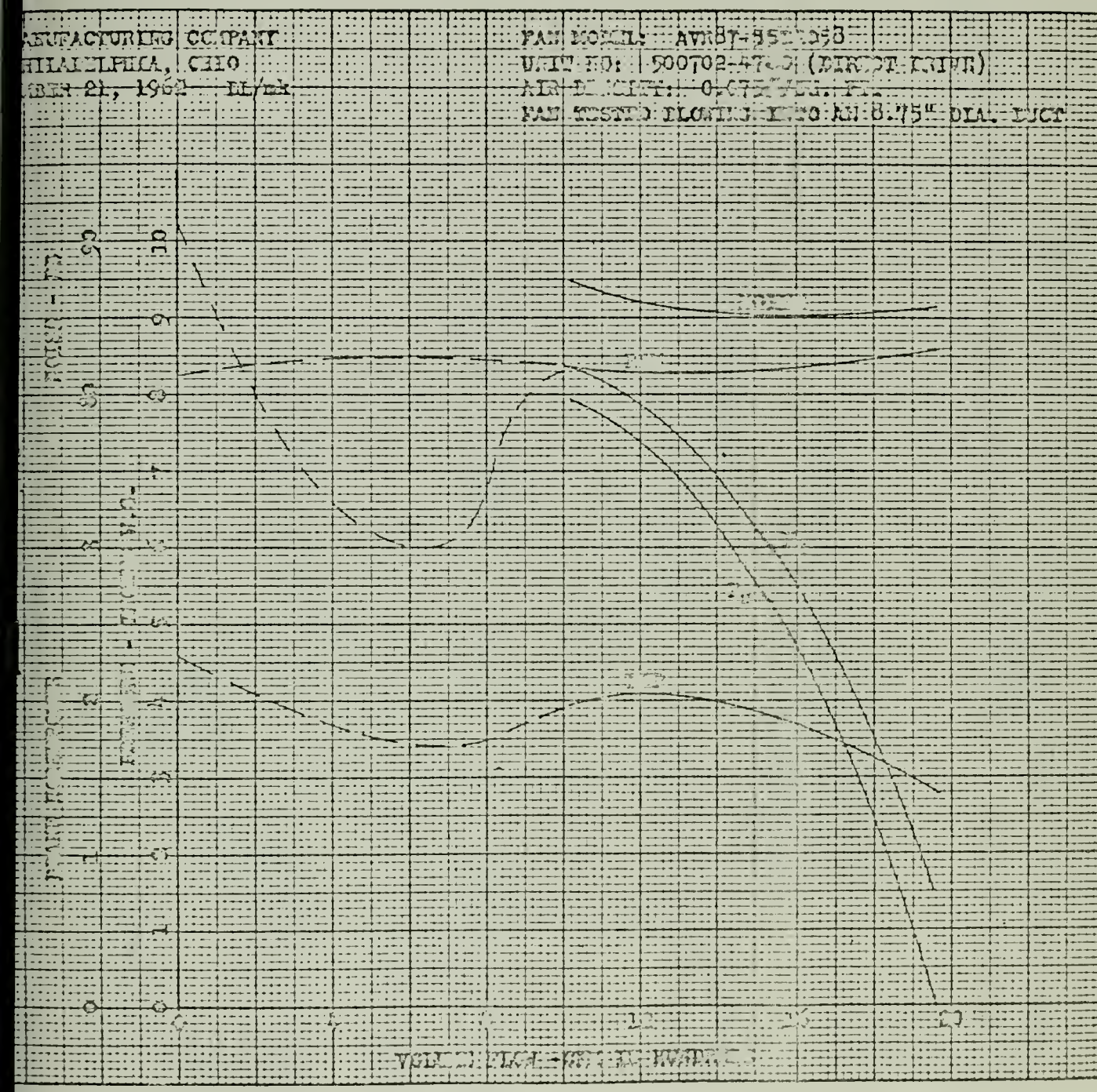


FIGURE 1

PERFORMANCE AND FAN MAP CURVES FOR THE JOY AXIVANE FAN (MODEL AVR 87-55D2058)

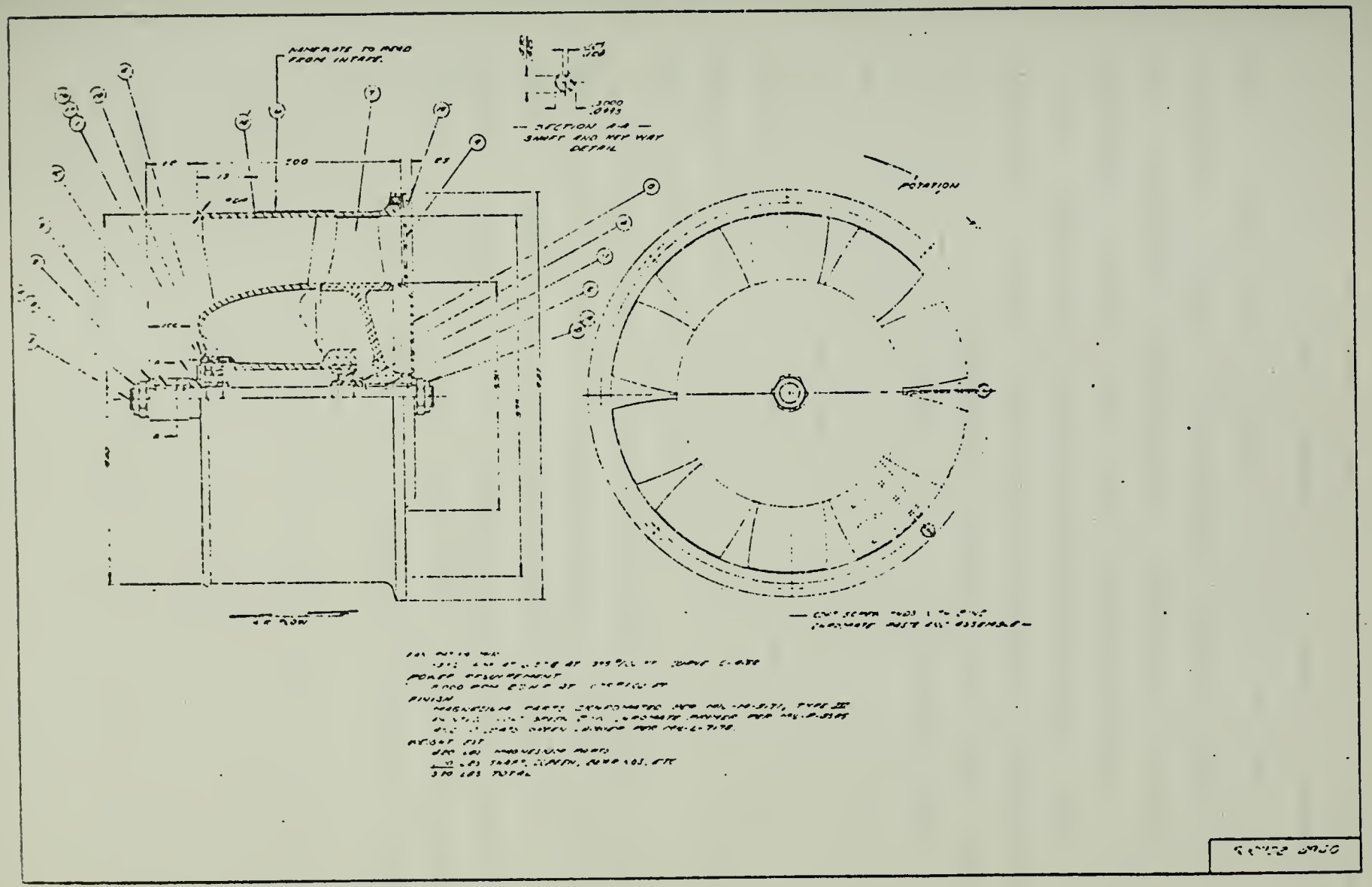


FIGURE 2
MANUFACTURER'S SPECIFICATIONS FOR THE JOY AXIVANE FAN

The first step used in arriving at the new fan maps was to establish a realistic leakage area. Once this leakage area was established a steady state efflux rate was established. Because in steady state operating conditions the influx and efflux rates must be equal the flow rate supplied by the lift fans in total was established. It was at this point that a second assumption was made. This assumption was that there were greater losses in the ducting supplying air to the bow seal and main plenum chamber than there were in the ducting supplying the rear seal. This assumption was based upon the fact that the ducting to the bowseal and main plenum had to carry the air forward approximately sixteen feet to their discharge orifices whereas the stern seal ducting was only a few feet long with only one curve in it to impede flow.

As a result the fraction of total flow assigned to the stern seal was greater on an individual fan basis than was the air supplied by the bow seal or main plenum fans. Another assumption was that the same map could adequately represent both the bow seal supply fans and those supplying the main chamber. This last assumption was based on similar duct lengths and construction.

Now knowing the individual fan flow rates and the actual plenum pressure a pressure drop in the duct for steady state conditions was established. This pressure drop was the difference between the known plenum operating pressure (24.84 lbs/ft^2) and the indicated fan discharge pressure

for that flow rate. This pressure drop was then scaled for different flow rates based upon the fact that pressure losses vary with the square of the flow rates. In this manner new fan maps were computed for the bow seal and main plenum, and the stern sea. These maps are presented in Figures 3 and 4.

The last step was to go back to the leakage area and make the slight adjustments needed to give the required plenum steady state pressure of 24.84 lbs/ft^2. The final leakage areas established were .08 ft^2 for the bow seal and 3.79 ft^2 for the stern seal.

In the original fan subroutine the horsepower generated by the fans is computed based upon the influx rate and the pressure differential between the atmosphere and the plenum. As the actual work done per unit time by the fans this figure can be misinterpreted as the actual power needed by the fans to generate printed work rate. This would only hold true if the fans operated with one hundred percent efficiency and there were no ducting losses. In actuality fans of this nature which supply relatively large volumes of air at low pressure rarely operate at over seventy percent efficiency and can achieve that only over an extremely narrow operating range. These physical characteristics of fans were well presented by R.D. Moyer in 1946 in Ref. 4.

For the fans that are used in the XR-3 the Joy Manufacturing Company has provided the fan's horsepower requirements

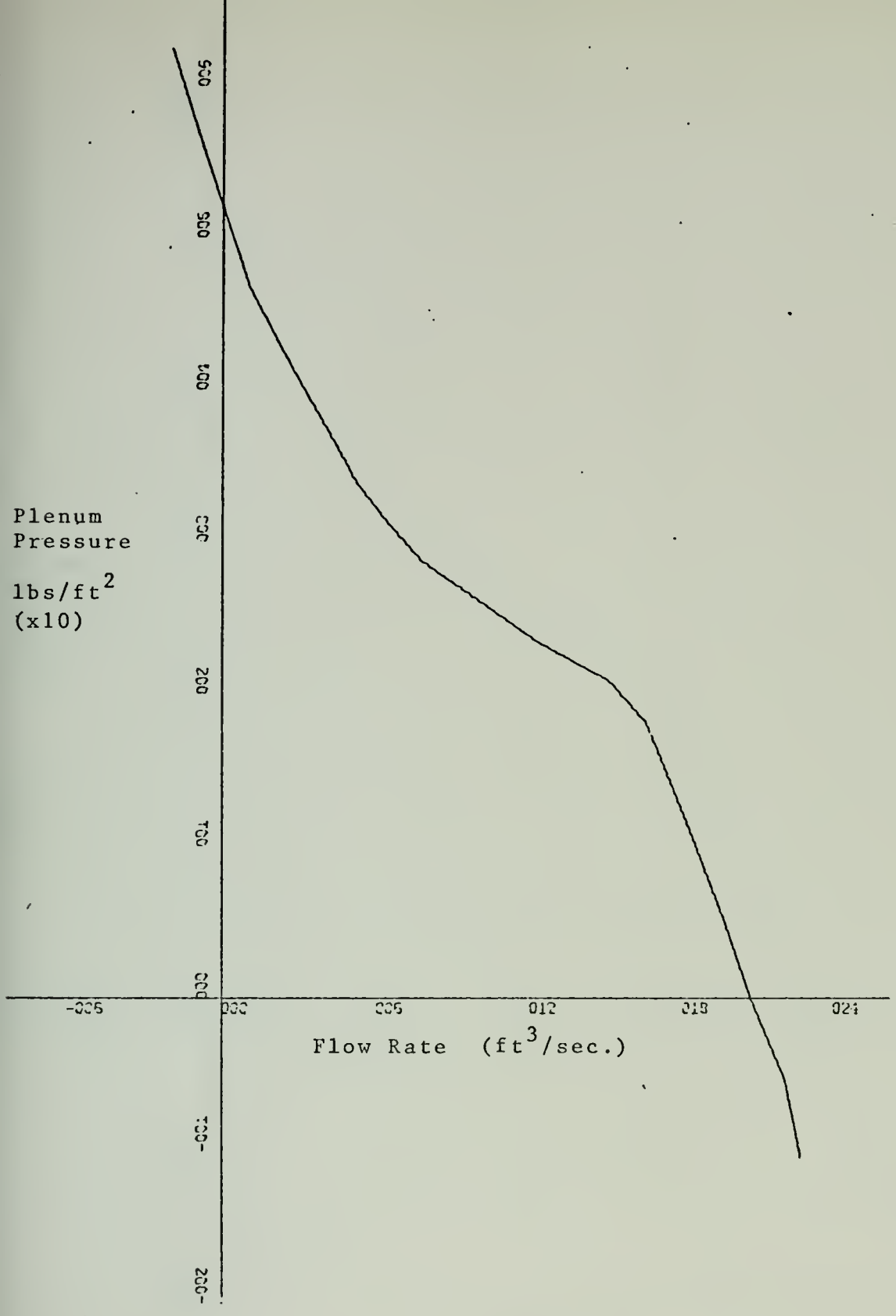


FIGURE 3

BOW SEAL AND PLENUM CHAMBER FAN MAPS, ADJUSTED FOR DUCTING LOSSES

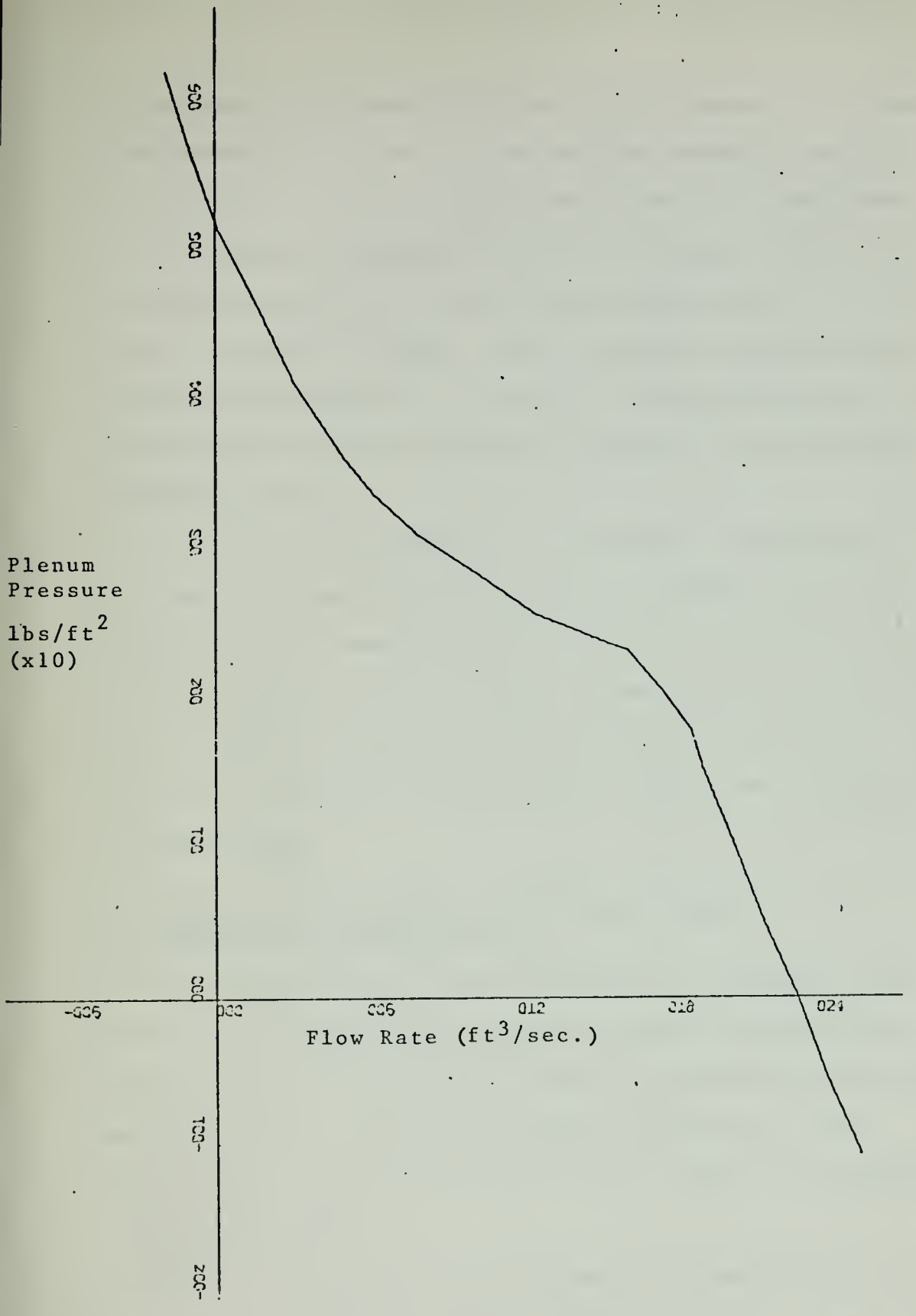


FIGURE 4

STERN SEAL FAN MAP, ADJUSTED TO ACCOUNT FOR DUCTING LOSS

on the same performance graph as the fan maps. This power requirement is plotted for the entire operating range of the fans and is fairly consistent at about 2 horsepower. This horsepower requirement does not change under the new fan maps since the fan map discharge pressures at the fan exhaust remains the same. This horsepower map was entered in the fan subroutine as a table of look up and actual power requirements were computed from it using flow rate as the entering argument.

In the COLFIL subroutine (the routine that prints out all data and draws all graphs) the fan power label was changed to "fan power (ideal)" to avoid possible confusion. In the fan subroutine the print option was modified to give the actual power required as well as the ideal power. Also the fan efficiency is computed and is given as an output of this subroutine.

C. SIMULATED PERFORMANCE COMPARISONS BETWEEN ORIGINAL AND NEW FAN MAPS

As stated earlier it was believed that changing the leakage areas and the fan maps would have a significant effect only when the computer model was run under conditions where the plenum volume underwent comparatively rapid fluctuations and/or the leakage areas around the periphery of the hull varied.

These assumptions were confirmed by simulated runs under varying sea conditions. In all these comparison tests the two XR-3 models used were identical except that the original

fan maps were replaced by the newly developed ones in one model. Both simulated craft were run using the original seals as developed in Ref. 3. Craft weight was 5813 lbs, center of gravity 9.57 feet from the stern, speed was held constant at 20 knots. All runs were made into ahead seas. The sea conditions chosen were irregular sea state 1, irregular sea state 2, regular seas 1 and regular seas 2. The latter two were so named because the amplitudes and frequencies chosen for these regular seas runs were the major component of irregular sea state 1 and irregular sea state 2 respectively. The actual amplitudes and frequencies for these runs are tabulated on page 27.

In the simulation runs into regular seas 1 dramatic differences were noted in the fluctuation of plenum pressure and heave accelerations. With the original fan maps, variations in plenum pressure were limited to about 2.2 lbs/ft^2 whereas with the new maps the variations were over 6.9 lbs/ft^2. This represents an increase in fluctuations of over 315 percent. Because the plenum normally provides over seventy percent of the supporting force for the craft similarly large variations were noted in heave acceleration both at the bow and at the center of gravity. Pitch motion, though, did not change much being less than .1 degree in both cases.

Results for the runs in other sea conditions are tabulated on page 28. The differences noted for the runs in irregular sea state 2 and regular seas 2 were not as great.

This has been attributed to the craft's ability to conform its attitude to the wave slope in the case of the longer wave lengths associated with greater sea states. This ability to conform then reduces the high frequency volumetric changes in the plenum chamber, thereby reducing pressure fluctuations. Figures 5 through 12 are the results of running both models in the simulated sea state one. By visually comparing the corresponding variances of the two models it is readily apparent that the fan maps do significantly change the performance characteristics of the model. By examining the table on page 28 it is also apparent that one must be careful in predicting behavior as the variation in measured variables does not vary directly with the sea conditions. The new fan maps have in effect defined a similar but different craft.

TABLE I. SEA STATE WAVE COMPONENTS

Run 1 Regular Seas 1 Heading 180

Wave Components	Amplitude (ft)	Frequency (rad/sec)
1	.0598	4.1526

Run 2 Regular Seas 2 Heading 180

Wave Components	Amplitude (ft)	Frequency (rad/sec)
1	.2721	1.8447

Run 3 Irregular Sea State 1 Heading 180

Wave Components	Amplitude (ft)	Frequency (rad/sec)
1	.0029	2.553
2	.0324	3.256
3	.0599	4.1526
4	.0558	5.2961
5	.0401	6.7545
6	.0262	8.6145
7	.0165	10.9867
8	.0102	14.0122

Run 4 Irregular Sea State 2 Heading 180

Wave Components	Amplitude (ft)	Frequency (rad/sec)
1	.0168	1.1786
2	.1464	1.4745
3	.2721	1.8447
4	.2668	2.3077
5	.2052	2.8871
6	.1410	3.6118
7	.0928	4.5185
8	.0600	5.6528

TABLE II SIMULATED XR-3 PERFORMANCE WITH DIFFERENT FAN MAPS

Comparison of XR-3 Loads and Motion Computer Program performance with original for maps with XR-3 with new fan maps are given below:

RUN	QUANTITY	XR-3 (original)	XR-3 (new)
1. Regular Seas 1	Plenum Pressure	24.8±1.09 PSF	24.8±3.45 PSF
	Pitch Angle	3±.05 deg.	2.7±.05 deg.
	Draft	6.25±.05 in.	5.9±.1 in.
	C.G. Acceleration	±.04 g	±.15 g
2. Irregular Sea State 1	Plenum Pressure	24.8±2.0 PSF	24.8±15 PSF
	Pitch Angle	3.2±.1 deg.	2.5±.2 deg.
	Draft	6.5±.05 in.	5.75±.1 in.
	C.G. Acceleration	±.07 g	±.4 g
3. Regular Seas 2	Plenum Pressure	23.75±5.75 PSF	24.8±7 PSF
	Pitch Angle	5.1±4.75 deg.	4.2±3.8 deg.
	Draft	7.25±2.3 in.	6.0±2.9 in.
	C.G. Acceleration	±.23 g	±.27 g
4. Irregular Sea State 2	Plenum Pressure	5 to 33 PSF	-5 to 40 PSF
	Pitch Angle	.8±2.2 deg.	.8±2.5 deg.
	Draft	8±6 in.	10±7 in.
	C.G. Acceleration	±.46 g	±.7 g

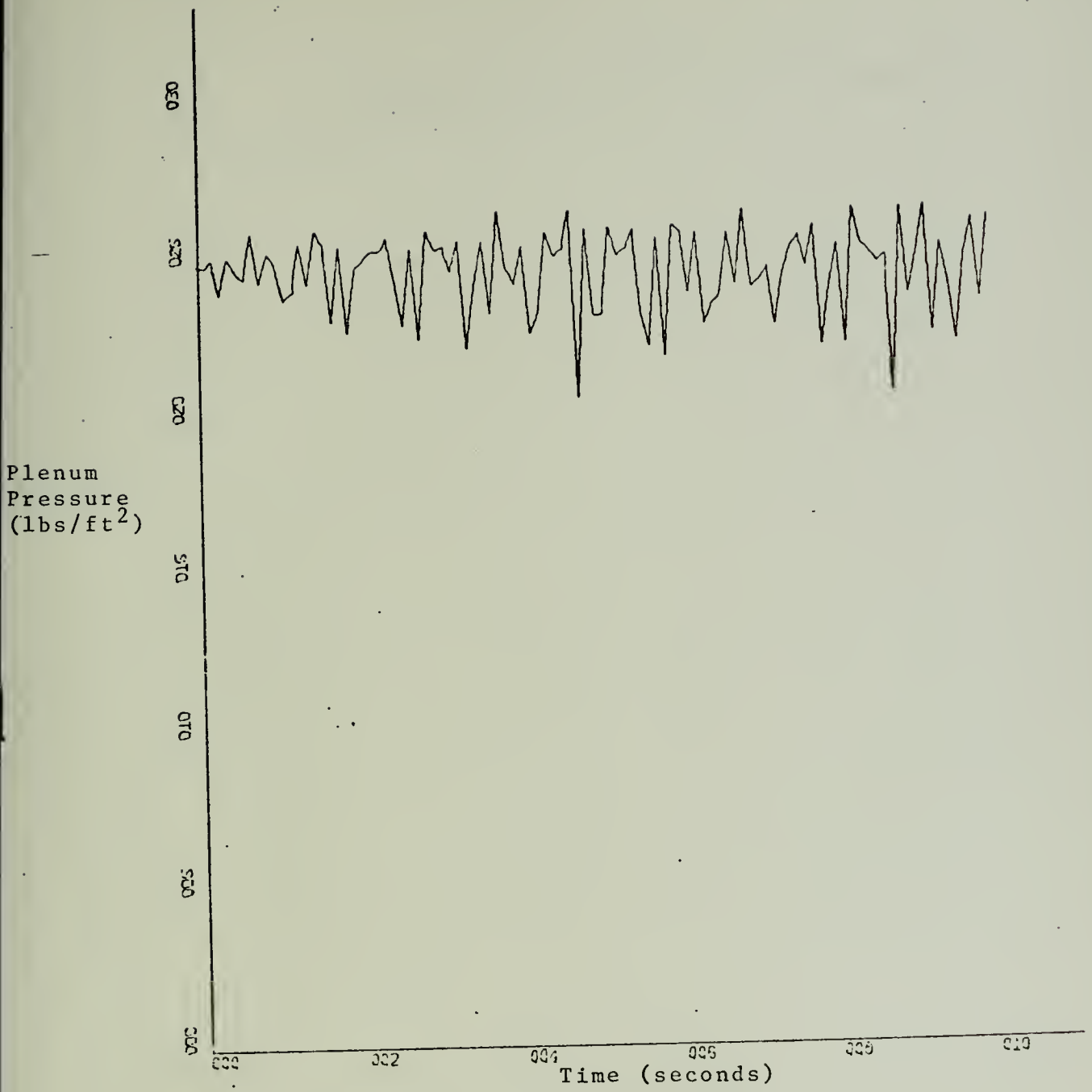


FIGURE 5

COMPUTER SIMULATION PLENUM PRESSURE VERSES TIME, SPEED 20 KNOTS
ORIGINAL FAN MAPS, SEA STATE 1

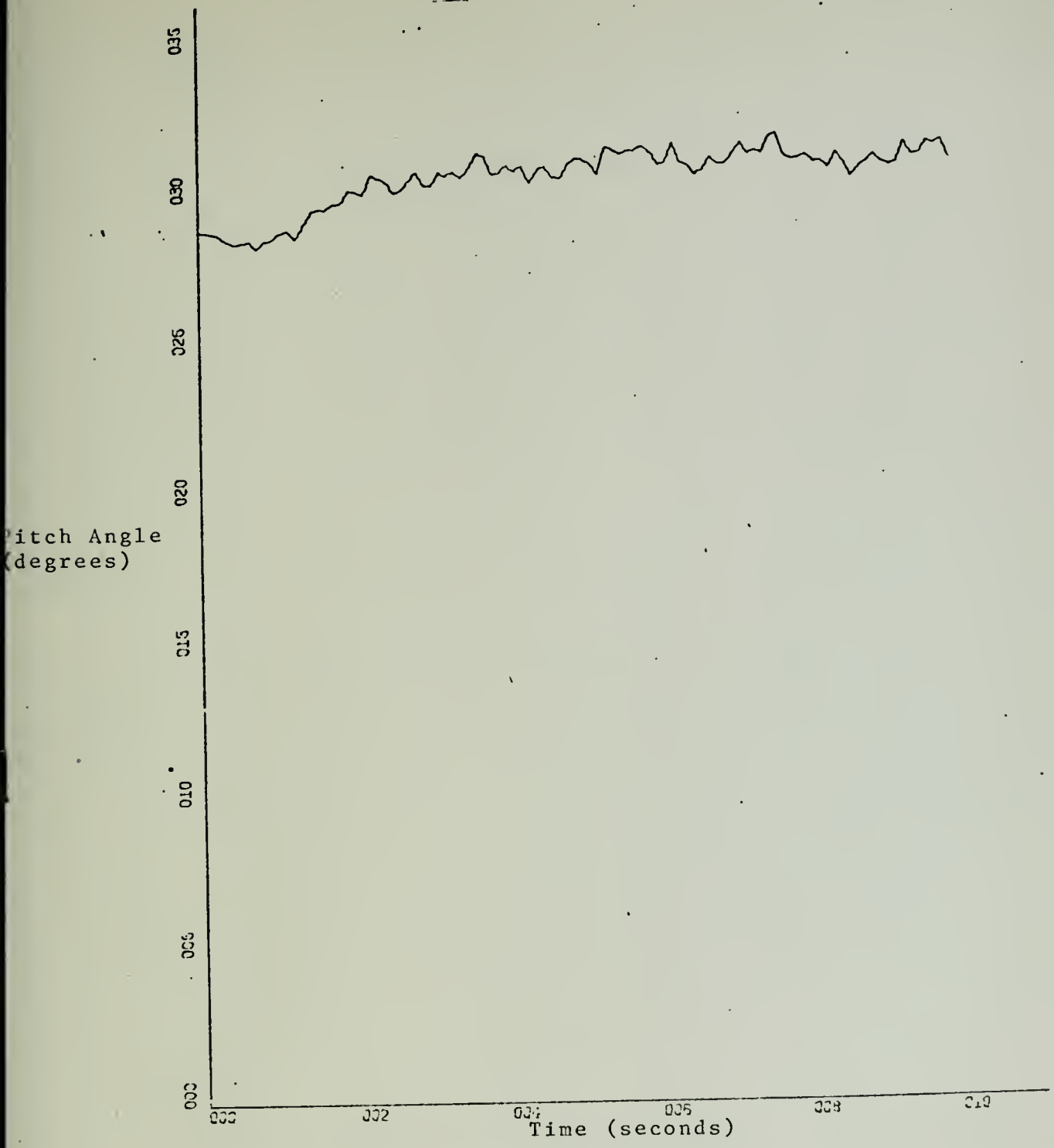


FIGURE 6

COMPUTER SIMULATION PITCH ANGLE VERSES TIME, SPEED 20 KNOTS ORIGINAL FAN MAPS, SEA STATE 1

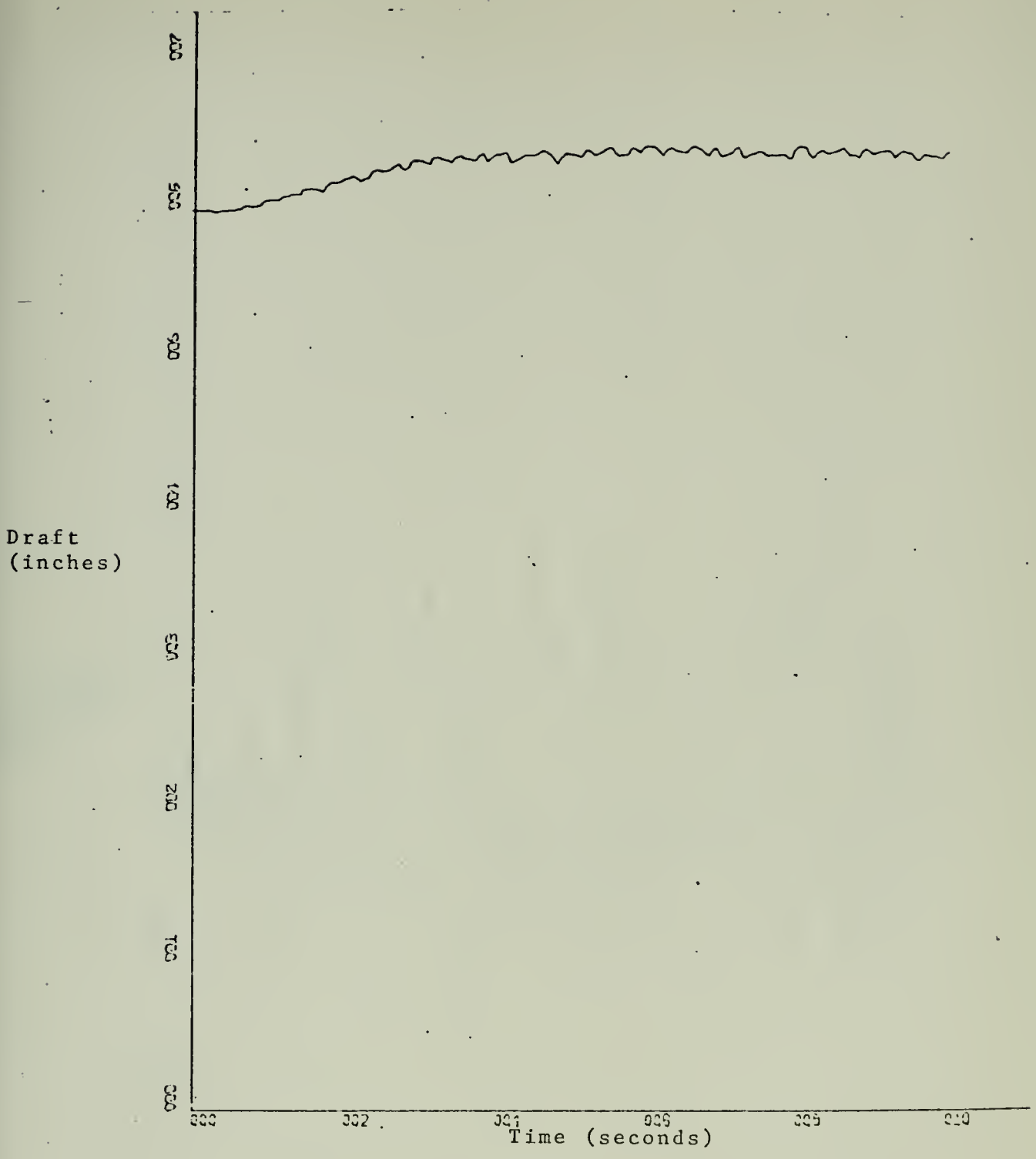


FIGURE 7

COMPUTER SIMULATION C.G. DRAFT VERSES TIME, SPEED 20 KNOTS
ORIGINAL FAN MAPS, SEA STATE 1

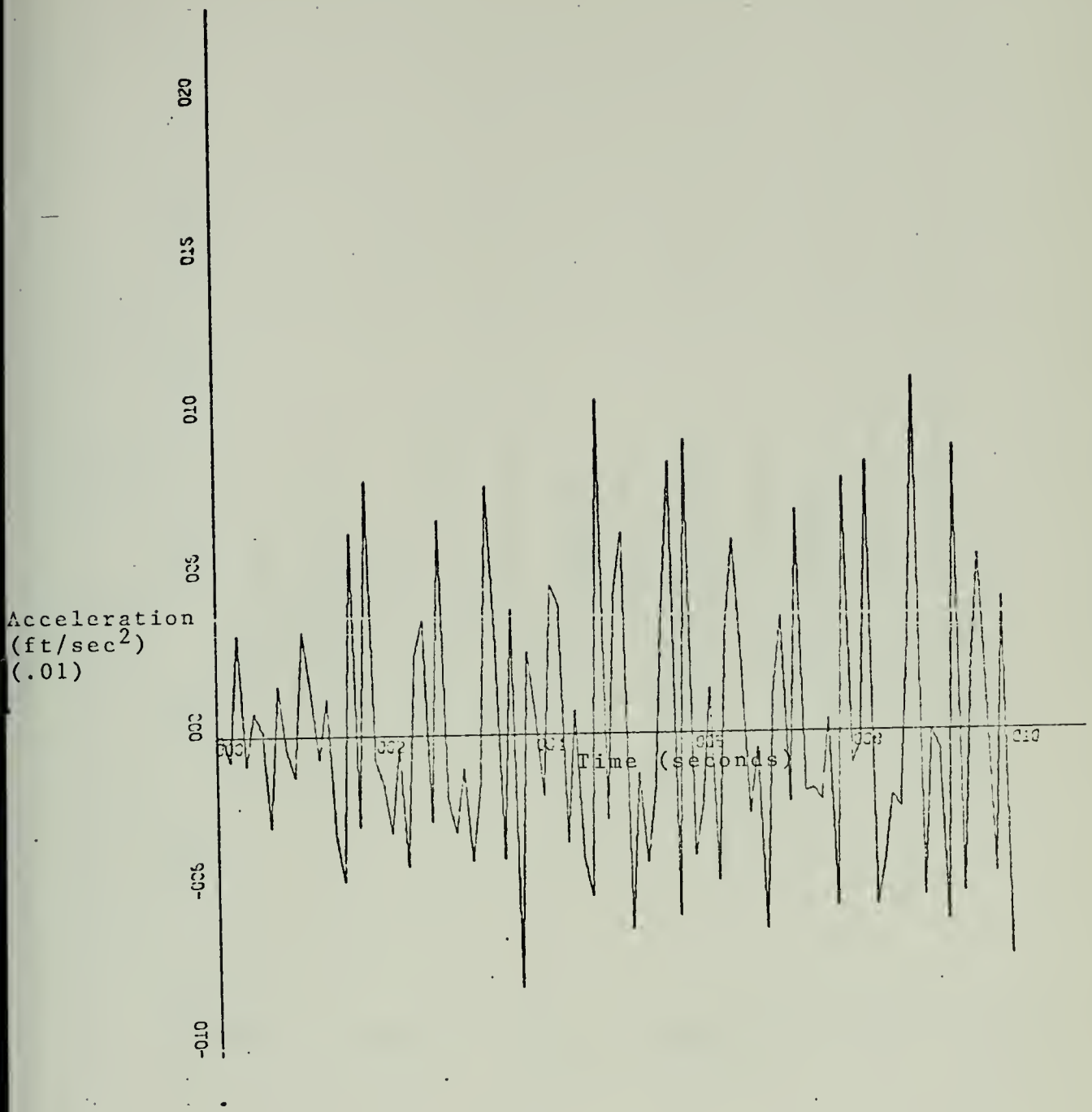


FIGURE 8

COMPUTER SIMULATION C.G. ACCELERATION VERSES TIME, SPEED 20 KNOTS
ORIGINAL FAN MAPS, SEA STATE 1

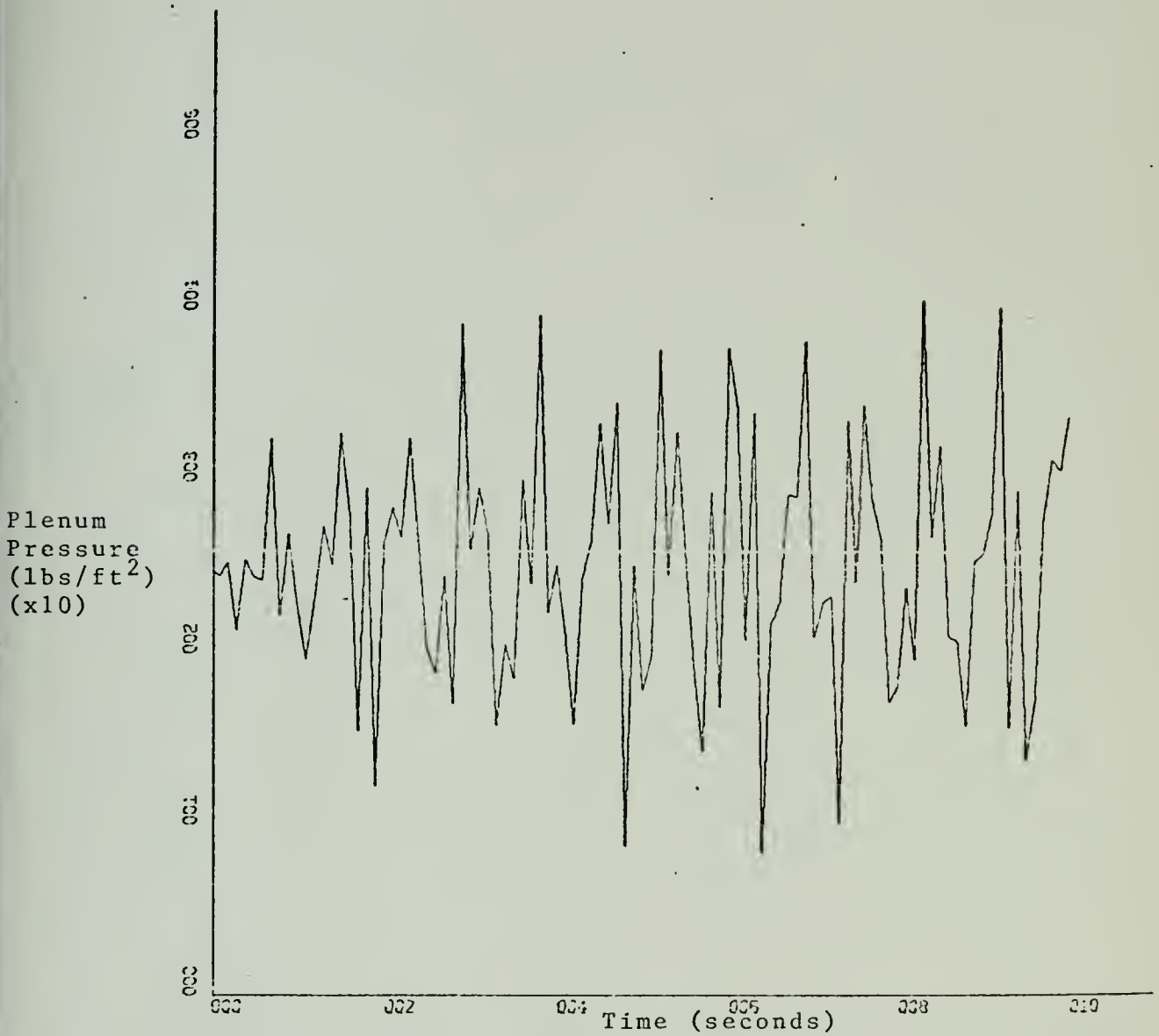


FIGURE 9

COMPUTER SIMULATION PLENUM PRESSURE VERSES TIME, SPEED 20 KNOTS NEW FAN MAPS, SEA STATE 1

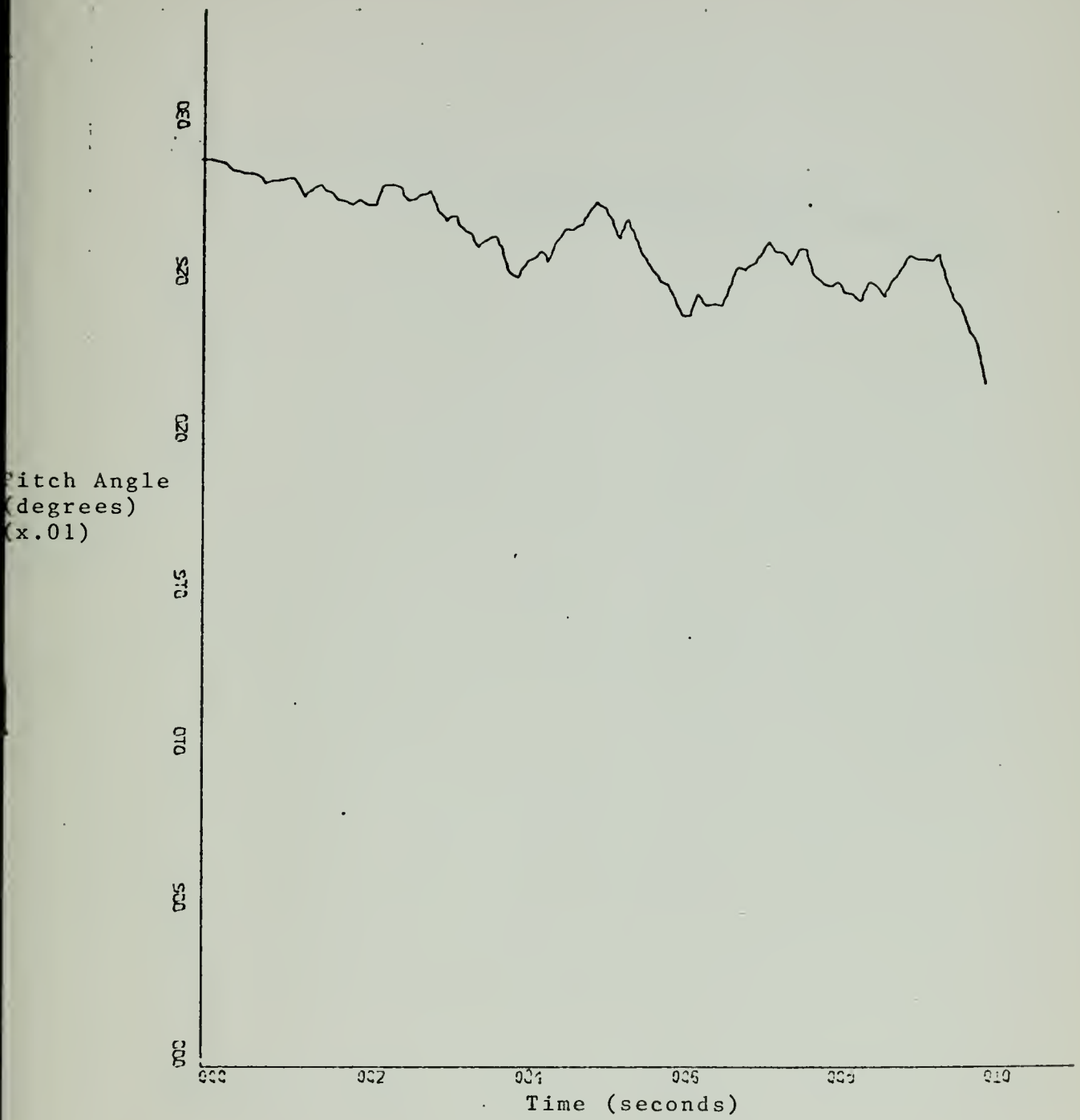


FIGURE 10

COMPUTER SIMULATION PITCH ANGLE VERSES TIME, SPEED 20 KNOTS NEW FAN MAPS, SEA STATE 1

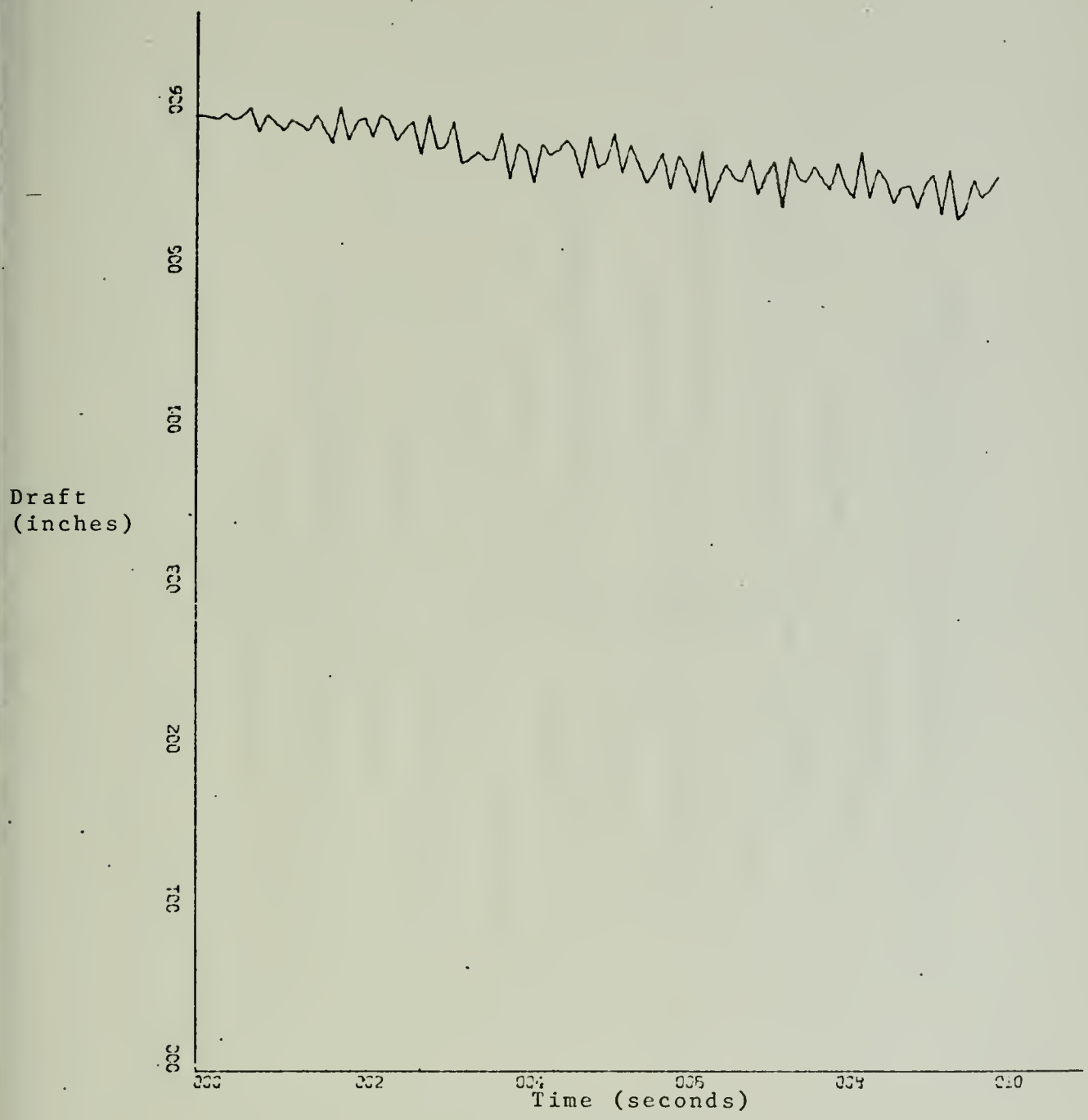


FIGURE 11

COMPUTER SIMULATION C.G. DRAFT VERSES TIME, SPEED 20 KNOTS NEW FAN MAPS, SEA STATE 1

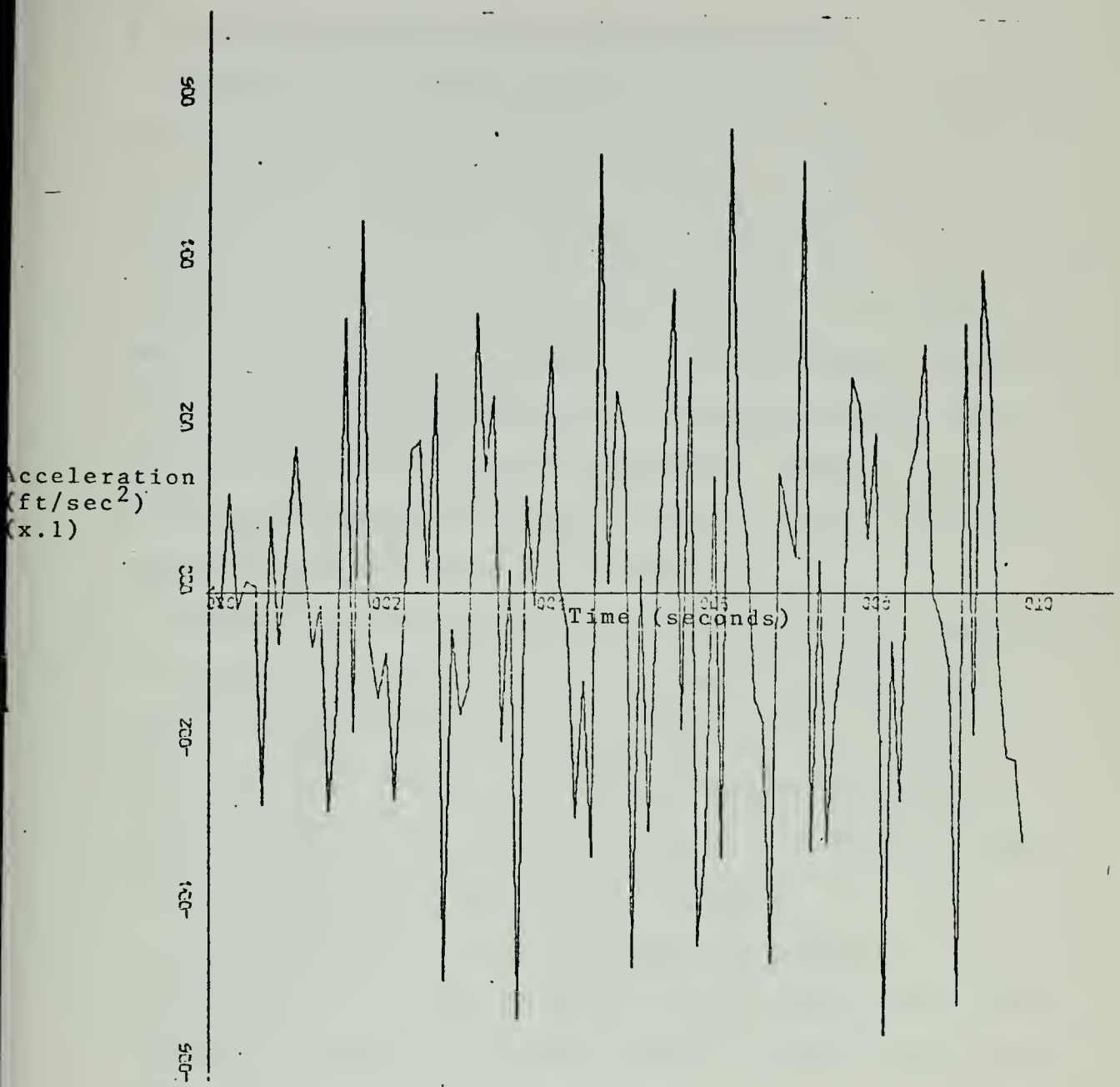


FIGURE 12

COMPUTER SIMULATION C.G. ACCELERATION VERSES TIME, SPEED 20 KNOTS
NEW FAN MAPS, SEA STATE 1

III. SEAL MODEL REFINEMENTS

A. INTRODUCTION AND BASIC MODELING TECHNIQUES

Through tests conducted aboard the XR-3 by the NPS test group headed by Associated Professor D.M. Layton of the Aeronautics Department it has been demonstrated that the forces generated by the seals have an appreciable effect on the overall performance of the test craft. By varying the lower travel limit of the bow seal and contouring its shape the steady state pitch angle can be changed as well as the thrust versus velocity characteristics. Although not as pronounced, changing the support cable length of the stern seal also affected craft trim conditions.

Because of the demonstrated steady state pitch sensitivity of the XR-3 to seal position limits as set by the support cables it was decided that more detailed modeling of the seals was needed before the overall response of the L&M computer model would reflect the behavior of the XR-3 under varying conditions of support cable length.

The original XR-3 seal modeling as presented in Ref. 3 was patterned after the rear seal in the L&M computer model of the Bell (100B) 100 ton CAB. This seal is of the "soft" pneumatic type and its representation is well covered by Kaplan, Bentson and Sargent in Ref. 2.

The pneumatic "soft" seal model is based on the assumption that this type of seal is unstiffened and non-rigid. The mass of the seal was considered so insignificantly small as

compared to the forces generated by the seal when it is in contact with the water as to have negligible effect on overall craft dynamics. The lifting forces generated by the seals were calculated by multiplying the wetted contact area of the seals by the pressure differential between the seal and the atmosphere for the bow seal and the plenum chamber and seal in the case of the stern seal.

Drag forces on the seals were considered to be due only to skin friction between the water and the seal. The equation used to compute these forces was

$$F_{x_{seal}} = - \frac{\rho u^2}{2} C_{df} A_{seal}$$

where ρ is the density of water, u the velocity of the craft and A_{seal} is the wetted surface of the seal. C_{df} is the drag coefficient and is calculated using the Schultz-Grünow formula

$$C_{df} = .427 / (\log_{10} Re - .407)^{2.64}$$

where Re is the Reynolds number computed based on the average wetted length of the seal and the Reynolds number is calculated by:

$$Re = \frac{u \times (\text{wetted length})}{1.28 \times 10^{-5}}$$

where 1.28×10^{-5} ft^2/sec is the kinematic viscosity of the water.

The actual construction of the seals is well described in Ref. 3. Each seal consists of two pneumatic lobes separated by a common membrane. The membrane has limber holes in it to equalize the pressure between the lobes. The lower surface of the bottom lobe is shaped by twelve steel battens that act as stiffeners. These battens are spaced uniformly across the bottom surface at right angles to the hinge line. It is this surface that comes in contact with the water, and will hereafter be referred to as the "leading face" of the seal.

The forward edge of the leading faces is hinged near the top of the plenum chamber allowing the seal to pivot about this line when waves are encountered.

The pressure in the seals is maintained by axial fans. The air is delivered by ducts that discharge into the top of the upper lobe. The seals in turn vent to the main plenum by means of ducting. Back pressure in the vent ducting can be controlled by butterfly valves that can be manually adjusted. Normally the seals are operated so that they maintain about 1-2 PSF more pressure than the plenum.

Downward travel limits of the seals are controlled by adjustable support cables attached to the rear edge of each steel batten at the trailing edge of the seal's leading face. In addition a second support cable is attached to each stiffener approximately midway between the hinge line and the trailing edge. Figure 13 shows a cutaway of the seals, only two cables are drawn in for clarity.

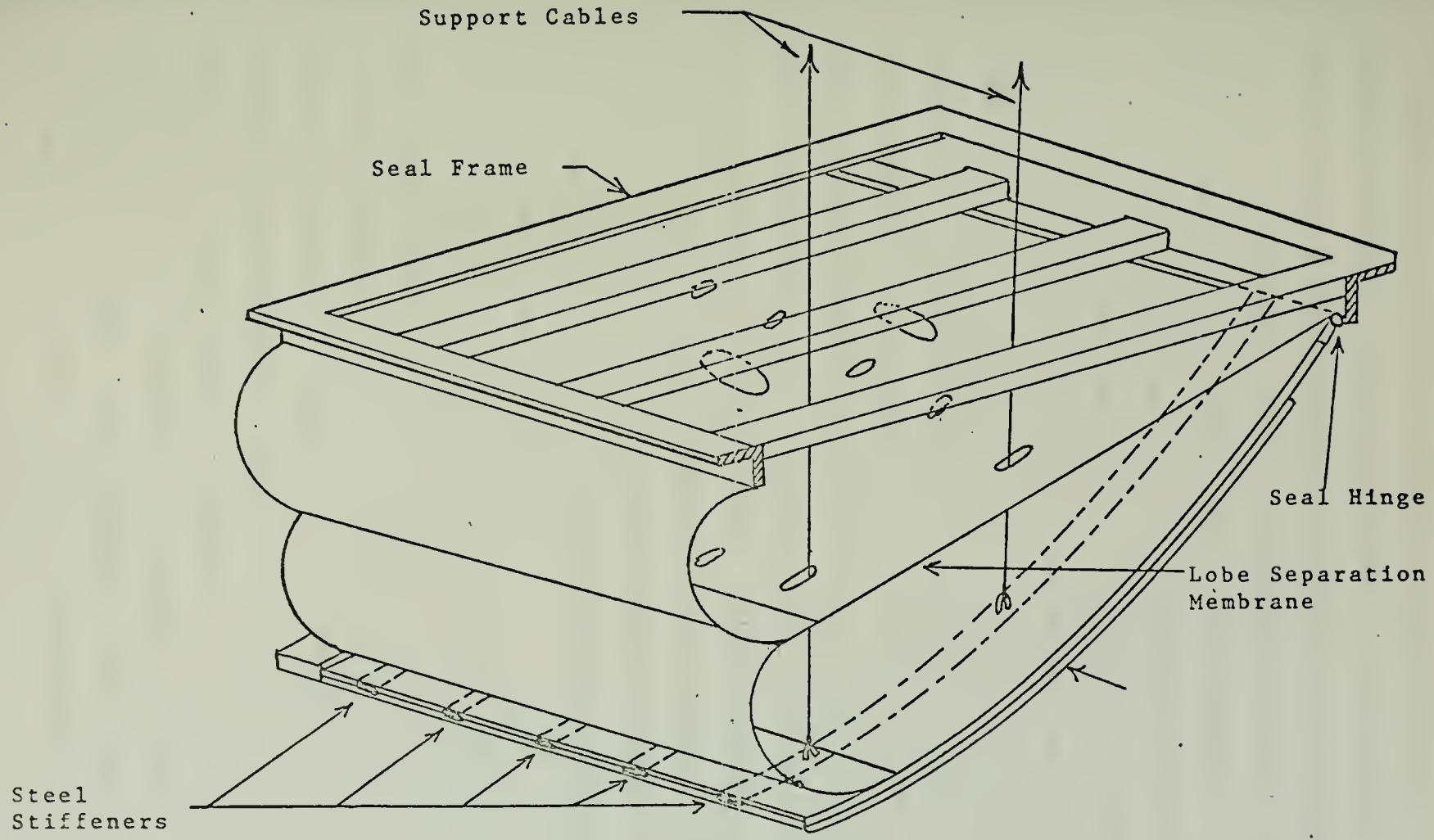


FIGURE 13

CROSS SECTIONAL VIEW OF PNEUMATIC SEAL AS INSTALLED ON THE XR-3

Both the bow and the stern seal extend the width of the plenum chamber and are identical in construction. The leading faces are approximately 49 inches long from hinge line to trailing edge. The perpendicular distance from sidewall keels to the hinge line is 22.5 inches.

As stated before the original modeling of the seals did not take into account any of the seal's ability to flex or pivot on its hinge. In addition no attempt was made to model the support cables and their ability to affect craft attitude. In the new modeling the support cables have been incorporated. In the stern seal modeling only the rear support cable is modeled since this seal rarely comes in contact with the water. In the bow seal subroutine both the rear support cables and the center support cables have been included since this seal does contact the water. Before any attempt at revising the seal subroutines could be undertaken it was necessary first to study the action of the seals while the craft was actually underway.

The semi-rigid construction of the seal dictated a highly complex distributed parameter model of the seals be developed if the seals were to be fully modeled without any approximations. In addition to the fact that practically all of the physical characteristic parameters of the seal such as spring constants for the steel stiffeners and fabric flexibility were unknown such a model would require an inordinate amount of calculation time in the computer. Since extra computation time was to be avoided simplifying assumptions had to be made.

To be accurate these assumptions or approximations had to be based on actual observations of the seal or on previously made approximations whose effect has already been investigated.

In Ref. 2 the approximation of eliminating seal dynamics and the setting of seal pressure at a constant level above plenum pressure has been thoroughly investigated and was incorporated in the original model of soft pneumatic seals. These approximations have been continued in the present seal modeling.

The other modeling approximations made were based upon actual observations made of the seals while the XR-3 was in motion. These observations are described below:

1. For small water perturbations (approximately 3 inches) the bow seal flexed and appeared to pivot slightly about the center support cable causing the angle at the hinge line to slightly increase, but almost insignificantly.

2. For longer perturbations the seal both flexed as described above and then began to pivot on the hinge. After the seal rose about six inches no additional flexing took place.

3. The bow seal maintained contact with the water at all times and never gaped because of an inability to follow wave motion.

4. The bow seals penetration of the water was practically independent of water motion in relation to the craft, but appeared to be inversely related to the craft's velocity.

When the XR-3 was at rest penetration was about five to six inches and when traveling at 20 knots appeared to be approximately 1 inch.

5. The stern seal rode out of the water while the craft operated above "hump" speed. The height of the air gap thus created appeared to remain almost constant at four to five inches. Water rarely contacted the seal.

Using the above described observations and the preceding simplifying approximations concerning seal dynamics and pressures both the bow and stern seal were modified to reflect the action of the actual seals.

The approximation given in Ref. 2 of equating the wetted length of the seal with the water height above the sidewall keel at the seal's trailing edge location was eliminated. In its stead a two-dimensional "table of look up" was developed which gave wetted length as a function of the immersion depth of the seal's trailing edge in the water and the seal's trailing edge deflection height above the keel at the trailing edge location. In other words if the seal was deflected upwards because of wave motion or pitching motion of the craft the deflection height of the trailing edge would increase and the seal's leading face would become more parallel to the water's surface thereby increasing the wetted area of the seal.

The "table of lookup" was constructed using the information obtained from a graphical deflection model similar to the one presented in Figure 14. In this model the leading face of the seal is represented in varying amounts of deflection height from full down (point A) to full up against the seal framework (point B). Full down is zero deflection and is where the trailing edge of the seal is even with the bottom of the sidewall keel, full up is maximum deflection. This deflection height was divided into segments of one inch for ease of computation. Points were marked upon each leading face line which represented the surface of the water on the leading face under varying depths of trailing edge immersion. The distance along the leading face to the trailing edge from these points then represented the length of the leading face that was immersed in the water or the "wetted length". The points for similar immersion depths were connected for the varying seal deflection heights and these construction lines are labeled with their corresponding immersion depths in inches along the zero deflection height leading face. The construction line corresponding to an immersion depth of zero inches is, of course, congruent with the trailing edge of the seal since if the seal did not penetrate the water to at least some degree there could be no "wetted length" unless the leading face was exactly parallel to the water's surface, which never occurs. These construction lines were drawn for immersion depths of the trailing edge of 0 to 5 inches.

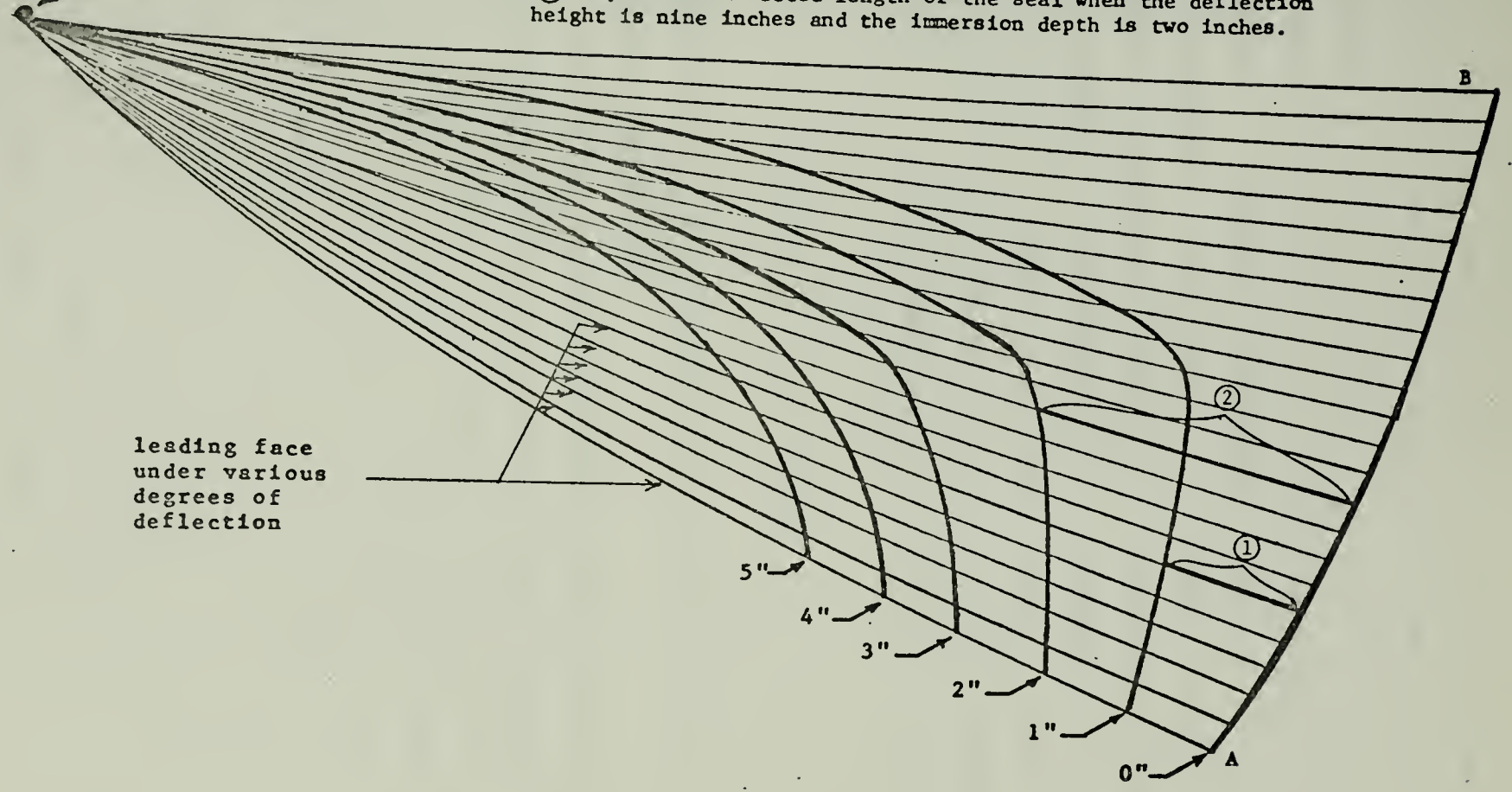

NOTE: length ① represents wetted length of seal with an immersion depth of one inch and a seal deflection height of five inches.
② represents a wetted length of the seal when the deflection height is nine inches and the immersion depth is two inches.
seal hinge point
B
leading face under various degrees of deflection
5"
4"
3"
2"
1"
0"
A
②
①

FIGURE 14

BOW AND STERN SEAL DEFLECTION MODEL (NOT TO SCALE)

The actual immersion depth of the trailing edge is calculated based upon the observation that at rest the immersion depth was approximately 5.5 inches and while traveling at 20 knots was estimated at a little less than one inch. Since the hydrodynamic force on the seal is proportional to the square of the craft's velocity the immersion depth was assumed to be approximately inversely proportional to some factor of the square of the speed.

Using 5.5 inches as the known immersion depth at zero zpeed and .75 inches at 20 knots, the following empirical formula was derived which gives reasonable results

$$D(\text{in.}) = 5.5/(1 + \frac{u}{25})^2$$

where D(in.) is the depth in inches and u is the velocity in feet per second.

Using the calculated immersion depth and the seals calculated deflection height the table is entered to give the wetted length. This table of look up is presented graphically in Figure 15. The non-linear nature of the curves is readily apparent. An important aspect of this table apparent in Figure 15 is that within about the first ten inches of seal deflection the wetted length of the seal remains fairly constant, especially if the craft is operating at speeds where the immersion depth is approximately one inch. This figure also shows that the maximum wetted length is equal to the length of the leading face (just over 48 inches).

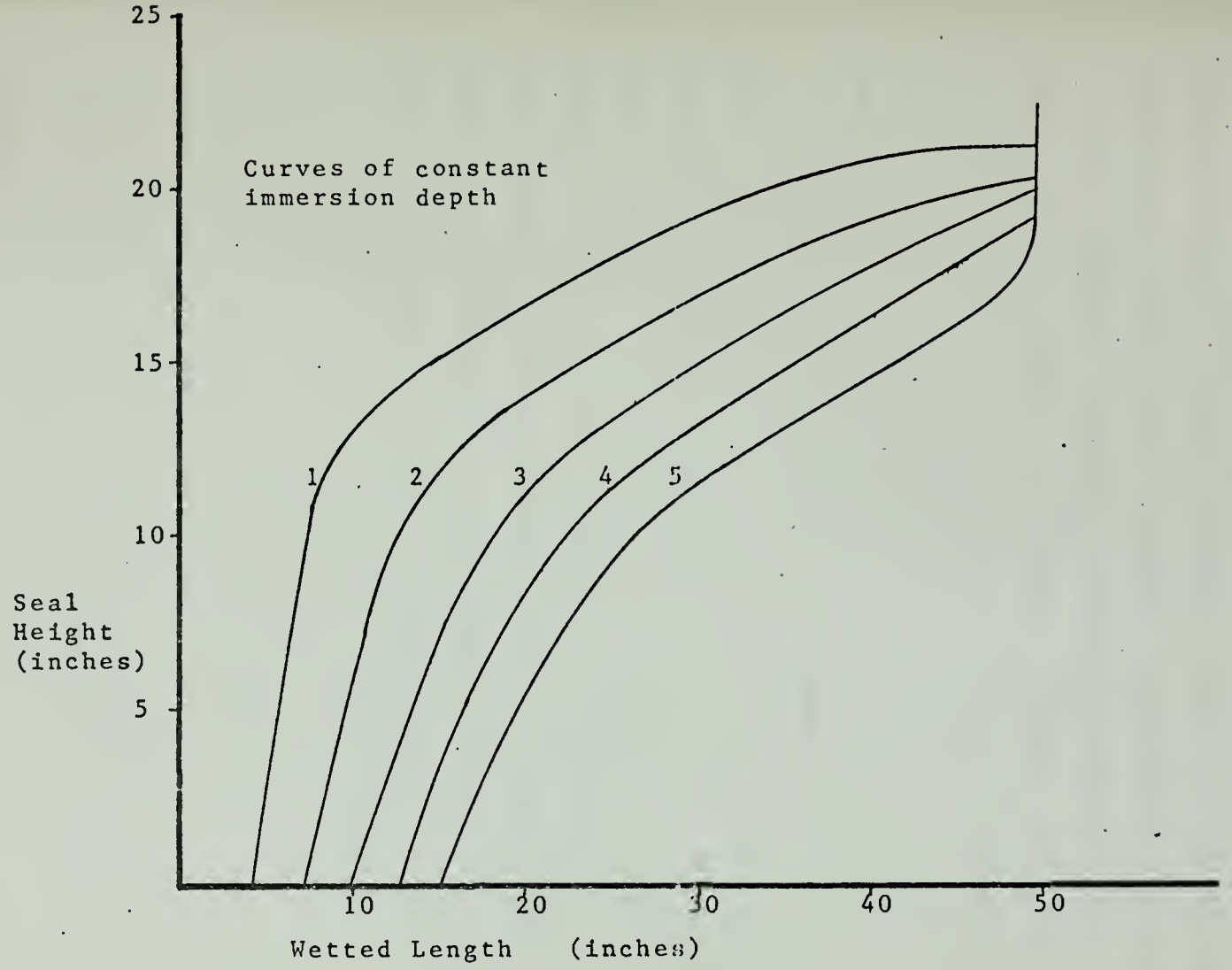


FIGURE 15

SEAL TRAILING EDGE HEIGHT ABOVE KEEL VERSES SEAL WETTED LENGTH

As the seal deflects and becomes more horizontal the wetted surface area becomes greater given a constant immersion depth.

This same "table of look up" is provided in the stern seal modeling but because the seal does not ride in the water an assumed "depth" had to be used as an entering argument.

The assumption was made that since the stern seal does not ride on the water its lifting force has to be the result of some form of air pressure. This force could only be generated by the impingement of air particles on the seal's leading face as they rushed to escape underneath the seal.

At this point an assumption was made that the effective wetted area occurred where the kinetic energy in the air mass was approximately one quarter that of the air escaping underneath the seal. As the air in the plenum is at such a pressure that it can be considered incompressible this would occur where the cross-sectional area was approximately two times the cross-sectional area beneath the seal. As the width of the plenum chamber is constant and the gap height is approximately 4.5 inches at all times the point on the seal where the cross-sectional area is two times the gap area is the point along the leading face where the height from the seal to the water is two times the gap height or about 9 inches. Subtracting the gap height gives an effective "phantom" immersion depth of 4.5 inches; this was rounded to five inches.

Lift forces generated by the stern seal were considered to be the product of the seal area found by using the above phantom immersion depth and the seal deflection height, and the pressure differential between the stern seal and plenum chamber.

The above lifting force calculation has only minimal effect on simulated performance of the XR-3 since the pressure between the seal and the plenum chamber is normally only one to two PSF. The drag forces on the stern seal are calculated in the same manner as they are in the bow seal subroutine but are subsequently set to zero since the seal rarely contacts the water.

B. BOW SEAL MODELING

Contained herein is a detailed analysis of the actual bow seal subroutine. It is coded in standard FORTRAN. By reviewing the actual subroutine the actual approximations used in the routine may be understood. A full listing of the BOWSL subroutine is contained in Appendix A along with the required entries in the data input statements.

```
(1)   DO 1 J=1,11
(2)   GAP(J) = 0.0
(3)   ELSKI(J) = 0.0
(4)   WETLEN(J) = 0.0
(5)   ELSKID(J) = 0.0
(6) 1 CONTINUE
```

The above statements (1 through 6) zero all variable arrays that will be used every time BOWSL is entered. GAP(J) is the height of the air gap at each station along the bow seal.

ELSKI(J) is the water height above the keel at the trailing edge of the seal. WETLEN(J) is the wetted surface length at each station. ELSKID(J) is the deflection height of the seal trailing edge measured from the botton of the keel of the craft.

```
(7)  ALBS = 0.0
(8)  FX = 0.0
(9)  FY = 0.0
(10) FZ = 0.0
(11) FK = 0.0
(12) FM = 0.0
(13) FN = 0.0
```

The preceding seven statements initialize the single valued variables that are computed each time BOWSL is entered. ALBS is leakage area of the bow seal. FX is the forces parallel to the craft's axis of symmetry (centerline). FY is the horizontal forces perpendicular to the FX forces. FZ is the vertical forces. FK, FM, FN are the moments about the Z axis, Y axis and X axis respectively.

```
(14) DELPBG = PBS - PB
(15) IF (DELPBG.LT.0.0)DELPBG=0.0
```

Equation 14 computes the pressure differential between the plenum chamber (PB) and the seal (PBS). This differential is actually fixed in INCON as an entering argument. Equation 15 assures that the seal differential pressure is never negative. This is reasonable since the seals vent to the chamber.

```
(16)    ARGO = ELMAXB/CORLEN
(17)    ANGO = ARSIN(ARGO)
(18)    X1 = XBS+ZBS*THETA-CORLEN*COS(ANGO)
```

The three equations above (16-18) establish the moment arm in the X direction from the craft center of gravity to the trailing edge of the bow seal. ELMAXB is the rear cable length. CORLEN is the chord length of the bow seal. XBS is the distance from the center of gravity to the bow. ZBS is the vertical distance of the bow hinge line below the center of gravity. Theta is the pitch angle of the craft.

```
(19)    Z1 = -Z-ABS+XBS*THETA-ELMAXB*COS(THETA)
```

Equation (19) establishes the moment arm in the -Z direction to the water's surface through which the drag forces act to create a moment about the Y axis.

```
(20)    DPTHFT = (5.5/(1.+(U/25.))**2.0/12.0
```

Equation (20) calculates the immersion depth of the seal based upon craft velocity, u.

```
(21)    IF(CENCAB.GT.1.1875)CENCAB=1.1875
```

Logical statement (21) sets the maximum length of the center support cable to 3 inches more than the maximum rear cable length, ELMAXB.

```
(22)     DO 3 K=1,N
           :
         3 CONTINUE
```

The above loop calculates for each seal partition point the water height above the keel ELSKl(K), the wetted length, WETLEN(K), and the seal deflection height ELSKID(K) in preparation to calculating the forces and moments.

```
(23)     DPFT(K) = DPTHFT
```

Equation (23) initializes the immersion depth of the seal.

```
(24)     ELSKl(K)=(ETA(3,K)-DTABX(K)*(XX(3,K)-Xl)-Zl)
                  +YY(3,K)*PHI+XLXPWV*WATSLP
```

Equation (24) establishes the water height above (or below) the keel at the bow. ETA(3,K) is the height of the water at the center of gravity above mean. DTABX(K) is the correction factor for moving this height away from the C.G. (Center of Gravity). (XX(3,K)-Xl) is the distance the correction factor has to act on. Zl is the height of the keel in relation to the C.G. YY(3,K) is the displacement of the partition from the craft center line. PHI is the roll angle. XLXPNV*WATSLP is the correction factor for the water slope caused by the plenum pressure acting for a finite period.

```
(25)    IF(ELSKI(K).GT.HINGHT) ELSKI(K)=HINGHT
```

Equation (25) limits the water height to the hinge height of the bow seal.

```
(26)    IF((HINGHT-ELSKI(K)+DPFT(K)).GE.ELMAXB)
        DPFT(K)=ELMAXB-HINGHT+ELSKI(K)
```

Equation (26) adjusts the immersion depth of the seal so that the seal can go no lower than that permitted by the rear cable ELMAXB.

```
(27)    IF(DPFT.LT.0.0) DPFT=0.0
```

DPFT is used in computing DPIN which is an entering argument into the wet length table BWSL. Therefore equation (27) limits this argument to a minimum value of zero.

```
(28)    ELSKID(K)=(ELSKI(K)-DPFT(K))*12.0
```

Equation (28) calculates the deflection height of the seal (ELSKID(K)) in inches based upon water height, ELSKI(K) and the immersion depth DPFT(K).

```
(29)    IF((HINGHT-ELSKID(K)/12.0).GE.ELMAXB)
          ELSKID(K)=(HINGHT-ELMAXB)*12.0
```

Equation (29) limits the downward travel of the bow seal to ELMAXB the rear cable length and adjusts the deflection height ELSKID(K) to reflect this lower limit.

```
(30)    DPIN=DPFT(K)*12.0
(31)    MM=DPIN
(32)    MM1=MM+1
(33)    MM2=MM1+1
(34)    DINC=DPIN-MM
```

The equations above, (30) through (34), establish parameters for entering the bow seal wetted length array, BOWSL. DPIN is the immersion depth in inches, MM1 is the lower limit table calling integer, MM2 is the upper table calling integer and DINC is the incremental difference.

```
(35)    GAP(K)=-ELSKI(K)+(HINGHT-ELMAXB)
```

Equation (35) computes the air gap height based on water height ELSKI(K) which is positive upwards and the limit of the seal travel (HINGHT-ELMAXB).

```
(36)    IF(GAP.LT.0.0) GAP=0.0
```

Equation (36) limits the gap to positive values.

```
(37)    IF(ELSKID(K).GE.0.0) GO TO 2
(38)    WETLEN(K)=ELSKI(K)
(39)    GO TO 3
```

Equations (37) through (39) set the wet length equal to the water height if it is negative. This computation is used in case one seal partition point has a negative value while the others on either side are positive.

```
(40)    MM3=ELSKID(K)
(41)    MM4=MM3+1
(42)    MM5=MM4+1
(43)    DLING=ELSKID(K)-MM3
```

Equations (40) through (43) establish the final two entering arguments for retrieving the four points needed from BOWSL to compute the wetted length. ELSKID(K) is the deflection height of the seal. MM4 is the lower entering integer based upon the deflection height, MM5 is the upper integer. DLINC is the incremental difference used for linear interpolation.

```
(44)    BWSL1=BWSL(MM1,MM4)
(45)    BWSL2=BWSL(MM1,MM5)
(46)    BWSL3=BWSL(MM2,MM4)
(47)    BWSL4=BWSL(MM2,MM5)
(48)    BWSLA1=(BWSL2-BWSL1)*DLINC+BWSL1
(49)    BWSLA2=(BWSL4-BWSL3)*DLINC+BWSL3
(50)    WETLEN(K)=((BWSLA2-BWSLA1)*DINC+BWSLA1)/12.0
```

Equations (44) through (50) identify the four points of the BWSL array which bracket the actual value of wetted length. Linear interpolation is used twice to find the average based on deflection height and once to find the final wetted length. The array BWSL was calculated in inches; thus, to convert to feet the final average is divided by 12.0.

```
(51)    DO 8 J=1,N
           :
           :
      8 CONTINUE
```

This loop makes all the force calculations based upon wetted length and seal position calculated previously. In

addition it calculates the leakage area based upon the steady state leakage area and the variable gap heights.

```
(52)    WETLAV=(WETLEN(J+1)+WETLEN(J))/2.0
(53)    IF(WETLAV.LE..001)GO TO 6
(54)    DPFTAV=(DPFT(J+1)+DPFT(J))/2.0
(55)    ELSKIA=(ELSKI(J+1)+ELSKI(J))/2.0
(56)    ELSKDA=(ELSKID(J+1)+ELSKID(J))/2.0
```

Equations (52) and (54) through (56) average the wetted length, immersion depth, water height and deflection height respectively, for each seal segment based on the values calculated for the stations on either side. Equation (53) routes the program around the remaining force calculations if the wetted length of the seal is zero or insignificant for calculation.

```
(57)    SEALHT=HINGHT-ELSKDA
```

Equation (57) is the calculation of the distance between the top of the seal's supporting frame and the bottom of the trailing edge of the seal.

```
(58)    DIFF=2.0*CENCAB-(SEALHT+0.5)
(59)    IF(DIFF.GT.0.5) DIFF=0.5
```

The DIFF equation (58) calculates the spring distance of the steel battens based upon the center support cable length CENCAB and the position of the seal, SEALHT. Equation (59) limits the spring movement to .5 feet or six inches, the point where rigid body analysis comes into full effect.

```
(60)     ARM1B(J)=X1+WETLAV/2.0
(61)     ARM2B(J)=ZS-ELSKIA+DPFTAV/2.0
```

Equations (60) and (61) calculate the moment arms in the X and Z direction respectively based upon the length to the trailing edge of the bow seal, X1, and half the wetted length, WETLAV/2.0, for ARM1B. ARM2B is based upon the height of the center of gravity ZS, the water height, ELSKIA and half the immersion depth of the seal, DPFTAV/2.0.

```
(62)     IF(DIFF.GE.0.25) GO TO 4
(63)     DFBS(J)=-DELP*DELYBS*WETLAV
(64)     GO TO 5
```

Equations (62) through (64) calculate the vertical force acting on the segment if the deflection difference is less than .25 feet or three inches. If the deflection difference is greater than .25 or 3 inches the vertical force equation has a spring constant term in it acting upon the moment summations about the hinge line.

```
(65)   4 FORLEN=XBF-WETLAV
(66)     IF(FORLEN.EQ.00) GO TO 5
(67)     ARGW=(HINGHT-ELSKIA)/FORLEN
(68)     IF(ARGW.GT.1.0)ARGW=1.0
(69)     ANGW=ARSIN(ARGW)
(70)     FORCOS=COS(ANGW)
(71)     GO TO 6
(72)   5 FORCOS=0.0
```

Equations (65) through (72) calculate the length of the seal not in contact with the water, FORLEN, and the angle which this length makes with the water ANGW. From the angle the cosine of ANGW is calculated, FORCOS, for future use in calculating the vertical moments about the hinge line.

```
(73)   DFBS(J)=-DELP*DELYBS*WETLAV-DELP*FORLEN*DELYBS
                *FORCOS*(FORLEN*0.5*FORCOS)/
                FORLEN*FORCOS+WETLAV/2.0))*
                ((DIFF-0.25)*4.0)
```

The above equation calculates the vertical force acting upon the bow seal by summing vertical moments about the hinge line and equating it to the moment created by one vertical force vector acting on the midpoint of the wetted surface. The term "(DIFF-0.25)*4.0" introduces a spring distance of three inches through which the vertical force transitions from being only based upon the product of the wetted area and the pressure differential to one based upon equalizing moments about the hinge line. After the seal bends this three inches it is assumed to be completely rigid and therefore if the seal is not undergoing accelerations, the moments must balance about the hinge line.

```
(74)   ARG=0.5*RHO*U*U*WETLAV*DELYBS
(75)   RESKI=U*WETLAV/ENU
(76)   CDTSKI=0.427/(ALOG10(RESKI)-0.407)**2.64
(77)   TSKIB(J)=-ARG*CDTSKI
```

The above four equations calculate the drag forces of the seal based upon the previously discussed Schultz-Grunow formula. RESKI is the Reynolds number,CDTSKI is the drag coefficient and TSKIB(J) is the drag force on the segment.

```
      7 CONTINUE
(78)    FX=FX+TSK1B(J)
(79)    FZ=FZ+DFBS(J)
(80)    FK=FK+DFBS(J)*YAVGB(J)
(81)    FM=FM-DFBS(J)*ARM1B(J)+TSKB(J)*ARM2B(J)
(82)    FN=FN-TSK1B(J)*YAVGB(J)
(83)    ALBS=ALBS+GAP(J)+GAP(J+1))*DELYBS/2.0
```

Equations (78) through (83) calculate the forces and moments for each segment and sums them to give total forces and moments. YAVGB(J) is the average distance off centerline of the individual segment.

```
(84)  8 CONTINUE
(85)    ALBS=ALBS+BLEAK
(86)    SQFAC=SQRT(2.*ABS(PBAR)/RHOINF)
(87)    QL=CFBS*ALBS*SQFAC*SIGN(1.,PBAR)
```

The last equations calculate the flow rate of air based upon the leakage area ALBS and the pressure differential between the plenum chamber and the atmosphere. BLEAK is the seal leakage entered in INCON to account for slight leakage where the seals do not quite maintain contact with the sidewall.

The remaining statements of subroutine BOWSL give the following values as printed output if the bow seal print switch is on, GAP, WETLEN, FX, FY, FZ, FK, FM, and FN.

C. STERN SEAL MODELING

The stern seal subroutine is covered in the same manner as the bow seal subroutine. The complete listing of the stern seal subroutine is contained in Appendix B along with instructions on the proper entries to be used on the data cards.

```
(1)      DO 1 J=1,11
(2)      GAP(J)=0.0
(3)      ELSKI(J)=0.0
(4)      ELSKIL(J)=0.0
(5)      AIRLEN(J)=0.0
(6)    1 CONTINUE
```

The above loop and equations zero all variable arrays that will change each time subroutine STNSL is entered as was the case in the bow seal subroutine.

```
(7)      EFDEP = 6.0
```

Equation (7) establishes the effective depth of the seal at five inches. This figure is used as an entering argument in the stern seal contour mapping array CTNSL.

```
(8)      ALSS=0.0
(9)      FX=0.0
(10)     FZ=0.0
(11)     FK=0.0
(12)     FM=0.0
(13)     FN=0.0
(14)     AGAP1=0.0
(15)     AGAP2=0.0
(16)     AGAPA1=0.0
```

The nine equations above zero all single valued variables that are computed each time STNSL is entered.

```
(17)     DELP=PSS-PB
(18)     IF(DELP.LT.0.0) DELP=0.0
```

The two statements above fix the pressure differential between the plenum (PB) and the stern seal (PSS). Equation (17) is first used to arrive at the difference between these two quantities and the logical IF statement is used to insure all values are non-negative. As in the bow seal

subroutine this is logical since the air supplied to the stern seal vents into the plenum chamber.

```
(19)    PBAR=PB-PINF
```

This equation establishes the pressure differential between the plenum (PB) and the atmosphere. It is used in computing leakage flow rates.

```
(20)    SINDIF=SINTH-COSTH*THETA
(21)    COSDIF=COSTH+SINTH*THETA
```

The above equations (20) and (21) establish the angle of the XR-3 with respect to the horizontal and the vertical, respectively.

```
(22)    X1=XSS+ZSS*THETA-XLF*SINDIF
(23)    Z1=(-Z-ZSS+XSS*THETA-ELMAXS*COS(THETA))
```

The above two equations establish lengths in the X and Z directions which are used to calculate the water height above the keel at the stern seal location.

```
(24)    N=NSTA(4)
(25)    DO 2 K=1,N
      2 CONTINUE
```

The above loop is used to establish the gap at each station and the phantom "wetted length" of the seal. NSTA(4) is the number of stations chosen for the seal and can be up to eleven, thereby defining ten seal segments.

```
(26)    ELSKI(K)=(ETA(4,K)-DETADX(K)*(XX(4,K)-X1)
                 -Z1)+YY(4,K)*PHI
(27)    IF(ELSKI(K).GT.HINGHT) ELSKI(K)=HINGHT
```

Equation (26) computes the height of the water above the keel at the stern seal location. ETA(4,K) is a length correction factor that is dependent on seal shape. Since in the case of the XR-3 the seal is flat across the hinge line this term is zero. DETADX(K) is a wave correction factor that is multiplied by the seal distance from the center of gravity (XX(4,K)-X1) to give the wave height at the stern seal location. The logical IF statement limits the water height to the top of the seal.

```
(28)    ELSKIL(K)=ELSKI(K)+GPS
(29)    IF(ELSKIL(K).GT.HINGHT) ELSKIL(K)=HINGHT
(30)    IF(ELSKIL(K).LT.(HINGHT-ELMAXS))
         ELSKIL(K)=HINGHT-ELMAXS
```

ELSKIL(K) is the height of the trailing edge of the stern seal above the keel. It is measured in feet. GPS is the air gap height that was observed to be constant under normal running conditions. It is .4644 feet. The logical IF statement (29) establishes the upper limit of seal deflection where it is stopped by the seal supporting framework. The second logical IF statement establishes the lower limit of seal deflection height.

```
(31)    GAP(K)=-ELSKI(K)+(HINGHT-ELMAXS)
(32)    IF(GAP(K).LT.0.0)GAP(K)=0.0
```

The equation (31) and logical IF statement (32) establish the gap height below the lower stop limit set by the support cable length ELMAXS.

```
(33)     MM1=ELSKIL(K)*12.0
(34)     MM2=MM1
(35)     MM3=MM2+1
(36)     DLINC=ELSKIL(K)*12.0-MM1
(37)     STNSL1=CTNSL(MM,MM2)
(38)     STNSL2=CTNSL(MM,MM3)
(39)     AIRLEN(K)=((STNSL2-STNSL1)*DLINC+STNSL1)/12.0
```

Equations (33) through (35) establish the entering arguments of the seal contour array CTNSL in the same manner as was done in the bow seal subroutine. AIRLEN(K) is the phantom "wetted length" and is given the name AIRLEN because the seal is supported by air.

```
(40)     N=NSTA(4)-1
(41)     DO 5 J=1,N
       5 CONTINUE
```

The above loop accomplishes the actual force and moments of each seal segment and totals the forces and moments. It also computes the average gap height based upon the gap heights of the individual stations.

```
(42)     ELSKIA=(ELSKI(J+1)+ELSKI(J))/2.0
(43)     ELSKLA=(ELSKIL(J+1)+ELSKIL(J))/2.0
(44)     AIRLAV=(AIRLEN(J+1)+AIREN(J))/2.0
```

The three above equations average the water height above the keel, ELSKIA;the average seal deflection height ELSKLA, and the average phantom wetted length AIRLAV.

```
(45)     AGAP=ELSKLA-ELSKIA
(46)     AGAP1=AGAP
```

Equation (45) establishes the average height of the air gap at the seal segment. AGAP1 is a variable used in further calculations.

```
(47)     IF(AGAP.LT.GPS)AGAP=GPS
(48)     IF(AGAP1.GT.GPS)AGAP1=GPS
```

The above logical IF statements establish the lower limit for AGAP at .4644 feet at the maximum value of AGAP1 at .4644 feet.

```
(49)     ARM1S=XX(4,J)+ELSKIA/2
(50)     ARM2S=ZS-ELSK1A
```

The above equations (49) and (50) calculate the moment arms through which the vertical lifting force acts to create the major component of the FM moment about the Y axis; the second equation creates the moment arm with respect to the C.G. through which the drag forces act.

```
(51)     DFSS(J)=-DELP*DELYSS*AIRLAV/(GPS/AGAP)**2.0
```

Equation (51) calculates the vertical force acting upon the seal and with the term (GPS/AGAP)**2.0 allows for this force to decrease with the square of the ratio of the actual gap width AGAP and the nominal width GPS. This is based on the assumption that the air exiting beneath the stern seal supports the stern seal and that the lift forces generated by the exiting air are inversely proportional to their velocity.

```
(52)    ARG=.5RHO*U*U*AIRLAV*DELYSS
(53)    RESKI=U*AIRLAV/ENU
(54)    CDTSKI=.427/(ALOG10(RESKI)-.407)**2.64
(55)    TSKIS(J)=-ARG*CDTSKI
(56)    TSKIS(J)=0.0
```

Equations (52) through (55) calculate the theoretical drag forces based upon the average phantom wetted length AIRLAV as if the seal was actually in contact with the water. The Schultz Grunow formula is used as in the bow seal routine to calculate the drag forces based upon the Reynold's number which is based on AIRLAV the average "wetted" length. Equation (56) removes this drag calculation since the seal is presumed to ride on a cushion of air and is hence negligible.

```
(57)    FX=FX+TSKIS(J)
(58)    FZ=FZ+DFSS(J)
(59)    FK=FK+DFSS(J)*YAVGS(J)
(60)    FM=FM-DFSS(J)*ARM1S(J)+TSKIS(J)*ARM2S(J)
(61)    FN=FN-TSKIS(J)*YAVGS(J)
```

The five equations above calculate the forces and moments of each segment and sums them for all the segments to give the total seal forces and moments.

```
(62)    ALSS=ALSS+(GAP(J)+GAP(J+1))*DELYSS/2.0
(63)    AGAP2=AGAP2+AGAP1
(64)    AGAPA1=AGAP2/J
```

The above equation (62) calculates the total gap area ALSS that is due to the seal reaching the downward limit of its travel and the gap thus increasing past its nominal value of .4644 feet. Equations (63) and (64) calculate the

average gap height including the nominal .4644 height and allows the nominal gap to close if the seal is slammed against its upper limit, the upper seal support framework.

```
(65)    ALSS=ALSS+ALEAK*(AGAPA1/GPS)
```

Equation (65) calculates the leakage area under the seal. ALSS is the leakage area due to the gap width increasing beyond the nominal .4644 feet. The term ALEAK is the nominal leakage area of 3.79 square feet normally observed. Multiplying ALEAK by AGAPA1/GPS allows this nominal leakage area to decrease if the seal is limited in its upward travel.

```
(66)    SQFAC=SQRT(2.*ABS(PBAR/RHOINF)
(67)    QL=CFSS*ALSS*SQFAC*SIGN(1.,PBAR)
```

Equations (66) and (67) calculate the flow rate based upon the leakage area and the pressure differential between the plenum and the atmosphere. The equation assumes orifice type leakage.

The remaining statements give print outputs of the terms GAP, AIRLEN, FX, FY, FZ, FK, FM and FN if the stern seal print switch is on.

IV. DATA ANALYSIS OF ACTUAL CRAFT TRANSIENT MOTION AND COMPUTER SIMULATION

A. INTRODUCTION

In order to verify the modeling changes made in the seals, data was collected on the XR-3 test craft for conditions of induced transient motion in pitch and roll. To induce roll action the test craft was sallied by shifting body weight laterally near the C.G. until maximum oscillations built up, then the forcing action was stopped. For pitch oscillations the chase boat was veered across the path of the XR-3 to produce a wave front with its wake. By having the XR-3 pass over the wake it was intended to induce a transitory pitch oscillation.

These attempts to produce a transient response cannot be viewed as entirely successful. The principal reason for the limited success was that it was extremely difficult to induce a large enough perturbation in either pitch or roll so that the normal background oscillations could be ignored. Figures 16, 17 and 18 are graphs of the roll and pitch motions[2] of the XR-3 when making its twenty knot calibration. The magnitude and frequency of the steady state pitch

---

[2]Figure 17 depicts the actual pitch angle of the test craft. Figure 18 is the same data with the steady state average pitch angle removed. This was done on all data to facilitate the measurement of the pitch oscillations superimposed on the steady state value of pitch angle.

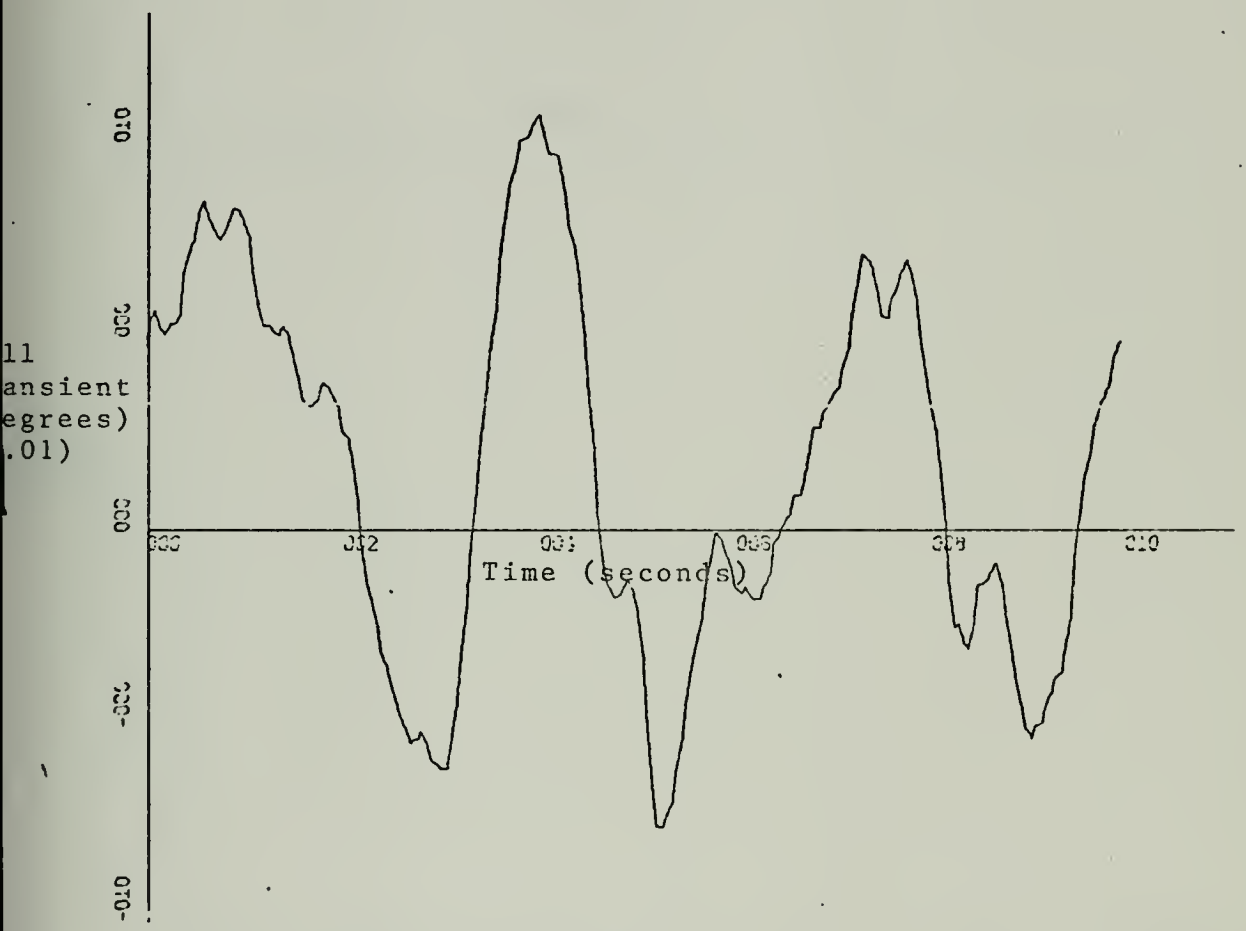


FIGURE 16

ROLL MOTION VERSES TIME, VELOCITY 20.429 KNOTS

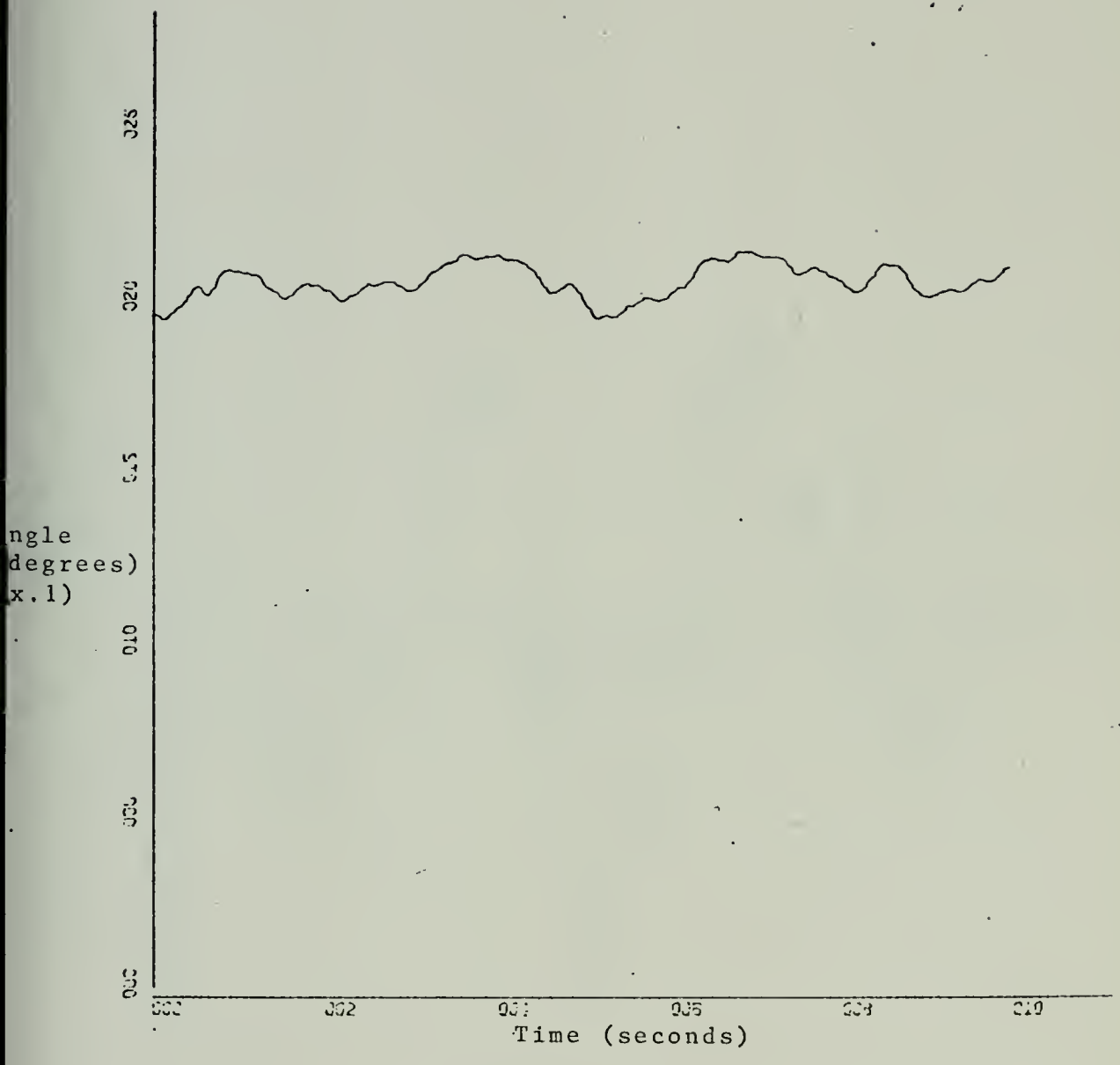


FIGURE 17

PITCH VERSES TIME, VELOCITY 20.429 KNOTS

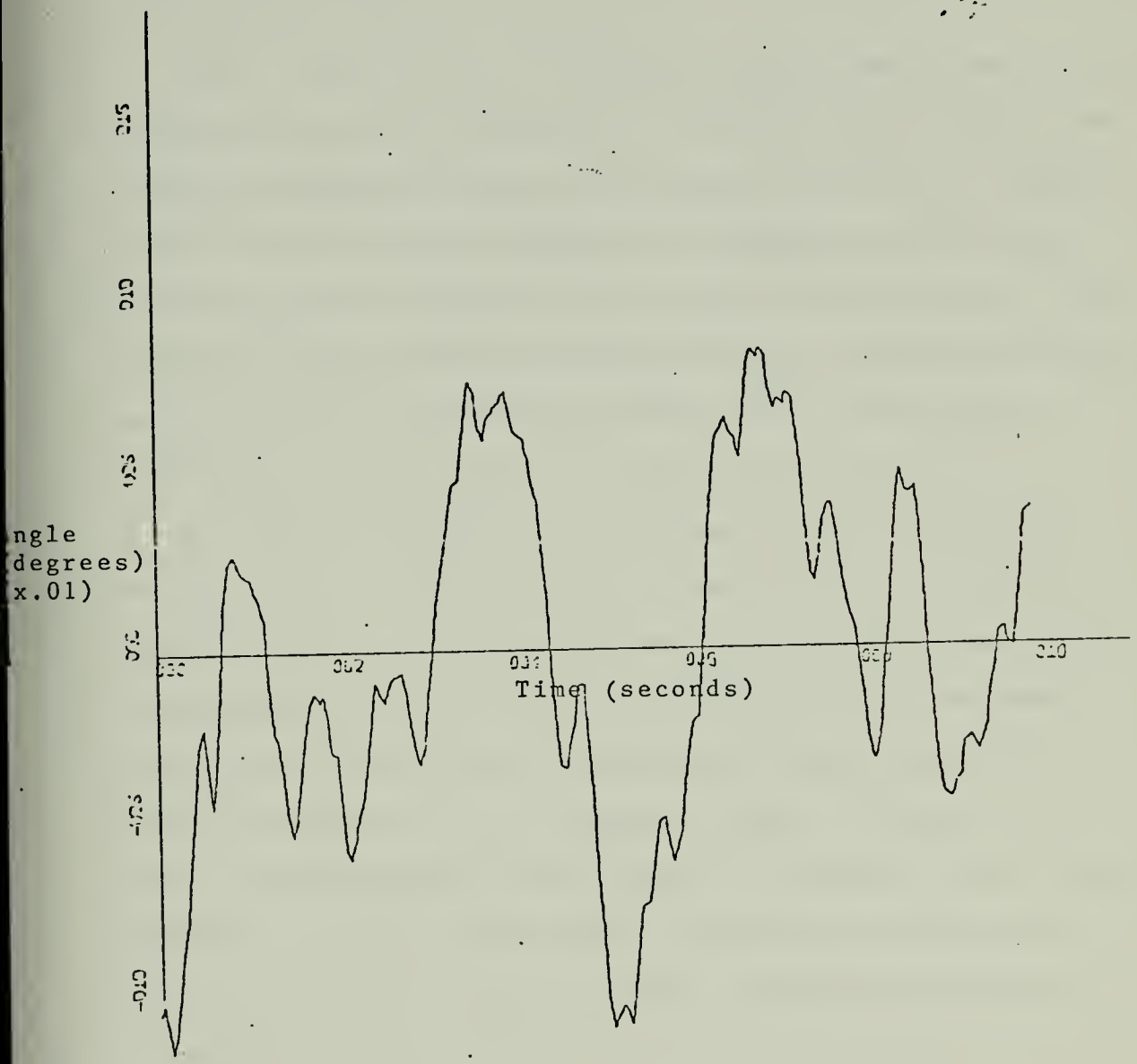


FIGURE 18

PITCH MOTION VERSES TIME, VELOCITY 20.429 KNOTS

oscillation shown in Figure 18 is approximately .08 degrees and .295 Hz respectively. The steady state magnitude of the roll motion shown in Figure 16 was approximately .075 degrees and its frequency was approximately the same frequency of the pitch motion, .295 Hz.

These steady state oscillations appear quite small until it is realized that the maximum roll perturbation that was able to be induced during any run was only about .4 degrees. Lower ratios between induced and background oscillations were the norm for both roll and pitch induced motion. The background oscillations in pitch and roll therefore could not be ignored when analyzing data, and deleteriously affected the measurement of decay time constants.

As stated before the attempt was made to introduce separately pitch and roll motion into the test craft and then record the transient response after the forcing action had passed or was stopped. After studying the processed data it was evident that it had been nearly impossible to affect transients in one variable (either pitch or roll) without introducing at least some oscillations in the other variable. In introducing pitch oscillations roll motion was greatly affected. This was caused because the wave front caused by the chase boat's wake always struck the test craft at an oblique angle and not perpendicular to the axis of symmetry of the craft. Only during those runs where the XR-3 was sallied was some modicum of success achieved in

isolating roll transient motion. The one run included in this report where sallying was used to induce roll transients is the one conducted at 11.79 knots. During the other two runs included (15.93 and 19.45 knots) the wake crossing method was used to force oscillations. This resulted in runs in which both roll and pitch transients could be studied at the same time.

In making comparison between the recorded data and that of the computer simulations both the original XR-3 model as presented in Ref. 3 and the new model which incorporates the new fan maps, new bow and stern seals and a water slope correction were used. This last modification is one which has been incorporated into the XR-3 program by LCDR G. T. Forbes, USN during his concurrent study and is reported in Ref. 5. The water slope modification is used to correct the water level in the plenum chamber based upon the fact that increased pressure in the plenum will tend to displace water after it comes in contact with the bow seal and passes into the chamber. This displacement since it does not take place instantaneously is a function of both time and pressure and hence results in a "slope" in the water as it passes through the plenum chamber. The purpose of using both the original and the new models was to gain an appreciation of the effects of the modeling changes made.

During all the runs made at Lake San Antonio with the XR-3 the water conditions were fairly calm, but the steady

state roll and pitch oscillations were always present in the processed data as reported previously. Figures 19 through 35 which are the graphs for all the runs clearly show this oscillation in both pitch and roll. Again it is emphasized that these oscillations precluded exact measurements of the decay time constants.

The method used to induce roll and pitch transient oscillations in the computer models was to offset the initial roll and pitch angle from the known steady state angles when the program was executed. These offsets would then decay as the craft returned to the steady state conditions for that speed. The magnitude of these offsets were taken from the recorded data. The point in time where this data was taken is marked on each graph of the test craft's recorded data by a dashed vertical line.

From known loading conditions the craft's weight during these runs was 6050 lbs. Its center of gravity was located 10.08 feet forward of the transom. Average plenum pressure was not available as this data was not recorded. The plenum pressure was assumed to be the nominal 24.86 PSF as reported in Ref. 3.

These inputs in the case of the original [Ref. 3] XR-3 model caused the craft to have a negative steady state trim angle which is readily apparent when looking at the graphs of the simulation runs of the original model (see Figures 22 through 28 for simulation runs at 15.93 knots).

Although it was recognized that this negative trim angle was not realistic the initial conditions were not varied to get a positive trim angle because it was desired to test each model with exactly the same physical characteristics. The actual value of the steady state trim was not the quantity that was to be studied. The quantity that was of interest was the transient response of the model as it arrived at that steady state value after an initial offset.

B. RUN DATA ANALYSIS

The first run was a calm water transient roll motion study at 11.79 knots. In this run the pitch offset was considered negligible. The roll induced oscillation was measured to have a negative magnitude of approximately .3 degrees. This roll offset was entered into both models with the following results. The decay time constant for roll motion was 4.6 seconds for the original XR-3 model and 5.6 seconds for the new model. The oscillation frequency was .752 Hz for the original XR-3 and .714 Hz for the new. Measured data gave the actual boat a frequency of roll oscillation of .29 Hz and a decay time constant of less than 1 second.

The second run was at 15.93 knots in calm water. This run had both roll and pitch perturbations. They were minus .25 degrees for pitch and a negative .27 degrees for roll. With these offsets the new XR-3 model gave a roll time constant of 4.1 seconds and a pitch time constant of

3.4 seconds. The frequencies of oscillation for the new model were .72 Hz for roll and .44 Hz for pitch. These same quantities were measured on the old model to be 3.1 seconds and 5.0 seconds for the roll and pitch time constants respectively, and in order, .76 Hz and .50 Hz for the roll and pitch frequencies. The same measured quantities from the recorded data gave something less than one second for both the roll and pitch time constants and .25 Hz and .22 Hz for the oscillation frequencies for roll and pitch.

The last calm water data was taken at 19.45 knots. The measured pitch offset was a positive .12 degree and a positive .45 degree for the roll offset. Again these values were imposed upon the initial steady state trim conditions to achieve a transient response.

From the two computer simulations the following results were obtained. Original model roll frequency – .76 Hz, roll decay time constant – 2.7 seconds, pitch frequency – .50 Hz, pitch time constant – 4.6 seconds. New model roll frequency is .72 Hz and decay time constant 4.3 seconds. Pitch frequency is .42 Hz and decay time constant is 4.4 seconds. The same data from the recorded tapes gave a pitch frequency of .28 Hz and with decay time constant of less than one second. Roll frequency was measured to be .28 Hz, and the roll decay time constant was estimated at less than one second.

From the above data taken on the three runs and the computer simulations thereof it is evident that the computer model neither in the original form nor in its new form accurately predicts roll or pitch transient motion under the conditions studied. Decay time constants for pitch and roll were generally four times too long in both simulation models. Pitch and roll frequencies of the computer models were generally too high by a factor of two. Table III gives this transient behavior of the XR-3 and both simulation models in tabular form.

Figure 19 is the actual roll response data for Run 1 collected at 11.79 knots. Figures 20 and 21 are the computer simulation runs for the original and new model for this run depicting roll response. Recorded pitch and roll motion for Run 2 (15.93 knots) is given in Figures 22, 23 and 24 and the original model computer simulation of roll and pitch is in Figures 25 and 26 respectively. The response of the new model for Run 2 is recorded in graphs 27 and 28. Recorded data for Run 3 is given in Figures 29 through 31 with the computer model's simulations of pitch and roll given in Figures 32 through 35.

C. SIMULATION STUDIES OF THE TWO MODELS

In an effort to gain better knowledge of the total effect of the new modeling, both the old and the new models were given a positive three degree pitch offset from steady state calm water conditions. Both models were set at the

TABLE III. CALM WATER FORCED OSCILLATIONS RESPONSE

Run 1, Speed 11.79 knots

Variable	Measured XR3	Simulated Original Model	Simulated New Model
Roll Frequency	.29 Hz	.752 Hz	.714 Hz
Roll decay time constant	<1 sec	4.6 sec	5.6 sec
Pitch Frequency	-	-	-
Pitch decay time constant	-	-	-

Run 2, Speed 15.93 knots

Variable	Measured XR3	Simulated Original Model	Simulated New Model
Roll Frequency	.25 Hz	.76 Hz	.72 Hz
Roll decay time constant	<1 sec	3.1 sec	4.1 sec
Pitch Frequency	.22 Hz	.50 Hz	.44 Hz
Pitch decay time constant	<1 sec	5.0 sec	3.4

Run 3, Speed 19.45 knots

Variable	Measured XR3	Simulated Original Model	Simulated New Model
Roll Frequency	.28 Hz	.76 Hz	.72 Hz
Roll decay time constant	<1 sec	2.7 sec	4.3 sec
Pitch Frequency	.28 Hz	.50 Hz	.42 Hz
Pitch decay time constant	<1 sec	4.6 sec	4.4 sec

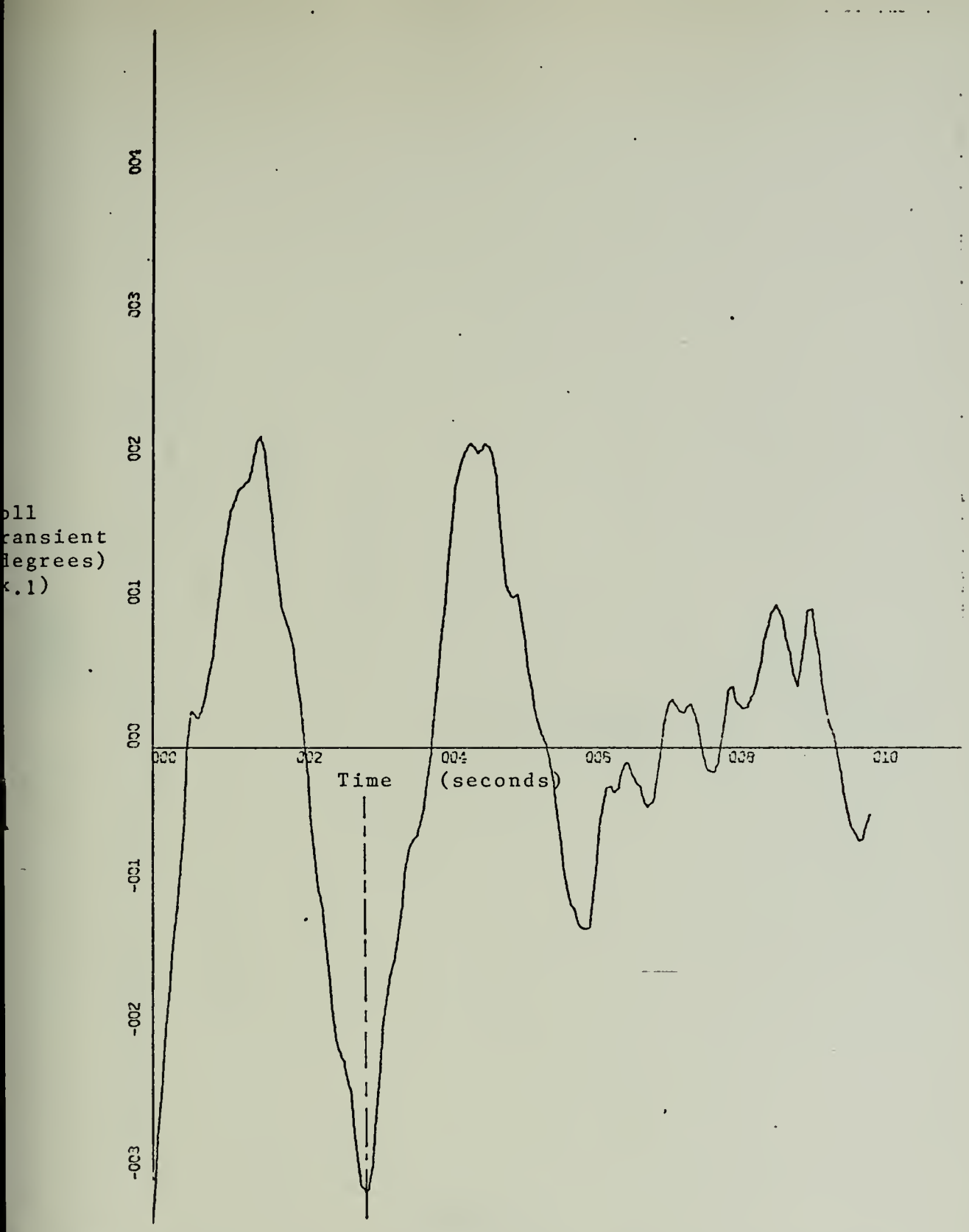


FIGURE 19

ROLL TRANSIENT VERSES TIME, VELOCITY 11.79 KNOTS

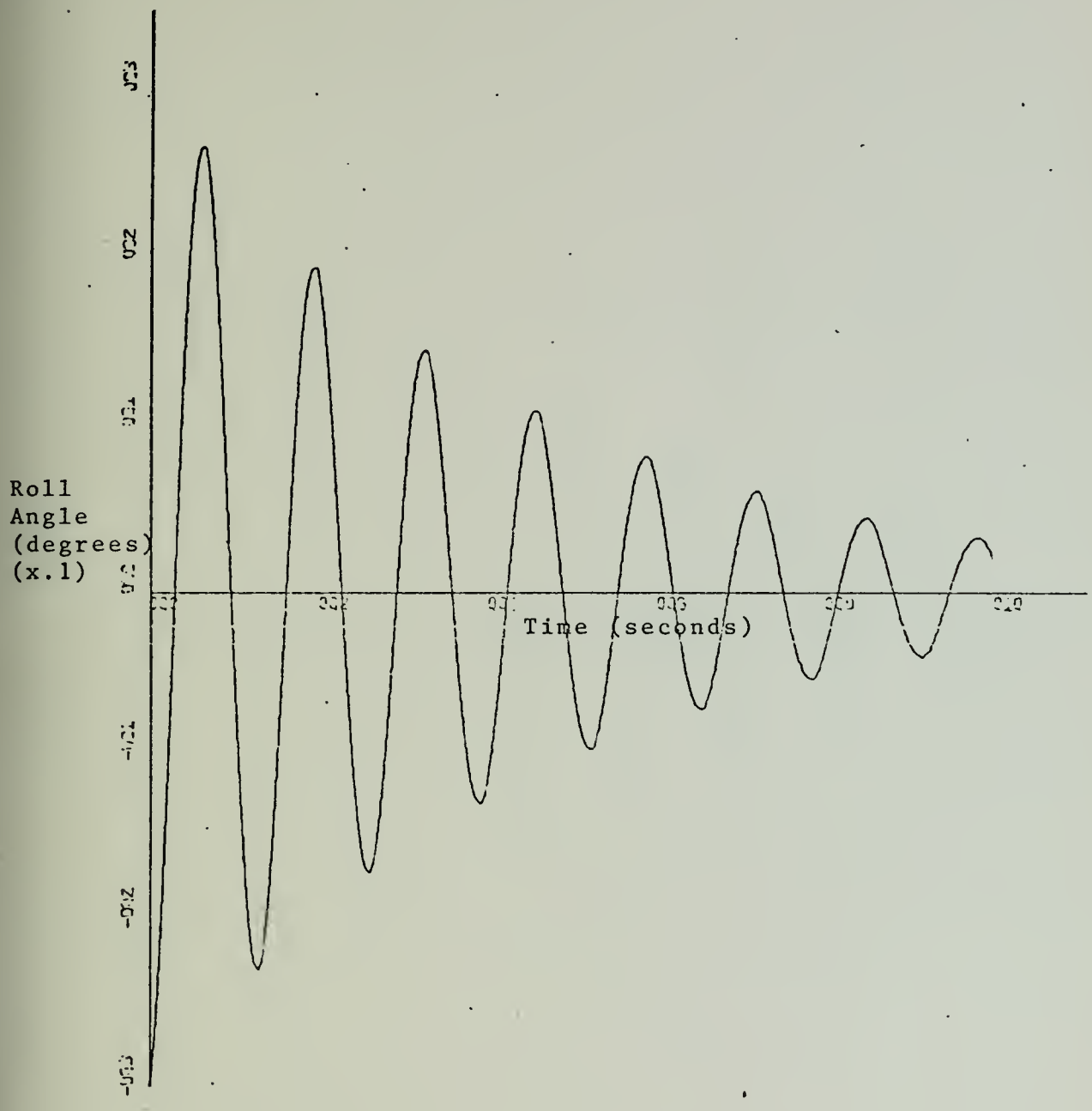


FIGURE 20

COMPUTER SIMULATION ROLL ANGLE VERSES TIME, 11.79 KNOTS
ORIGINAL XR-3

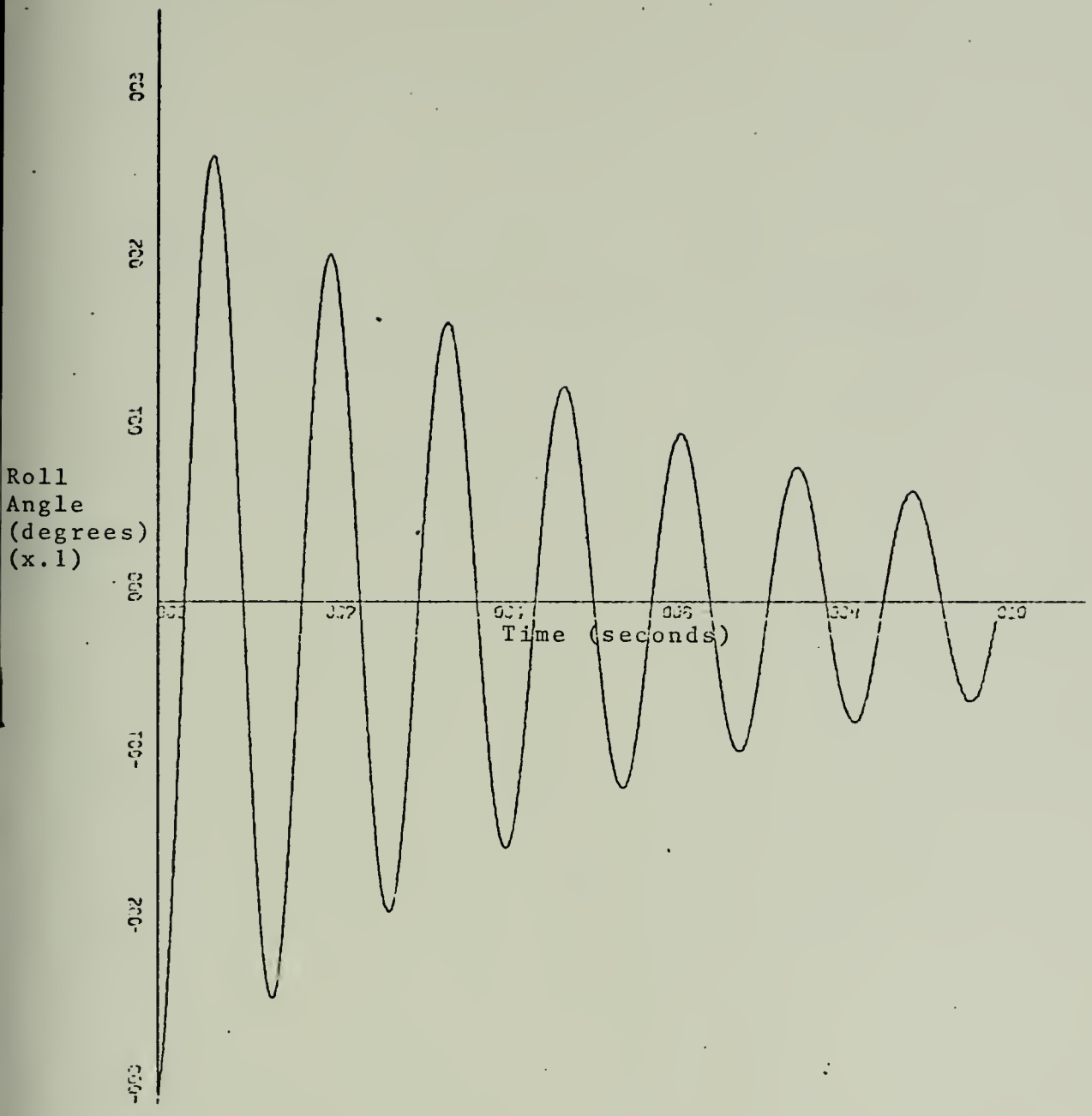


FIGURE 21

COMPUTER SIMULATION ROLL ANGLE VERSES TIME, 11.79 KNOTS
NEW XR-3

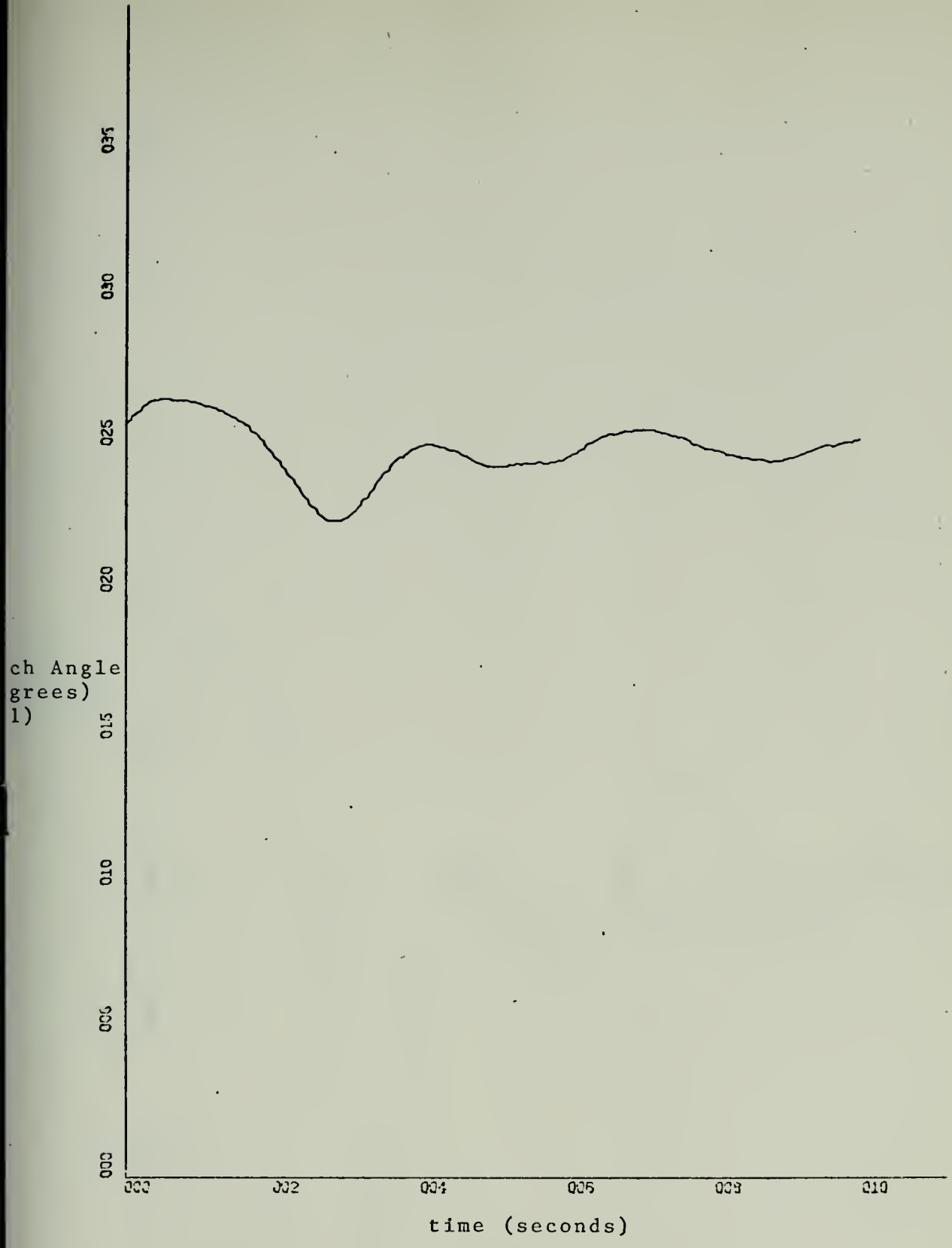


FIGURE 22

PITCH VERSES TIME, VELOCITY 15.93 KNOTS

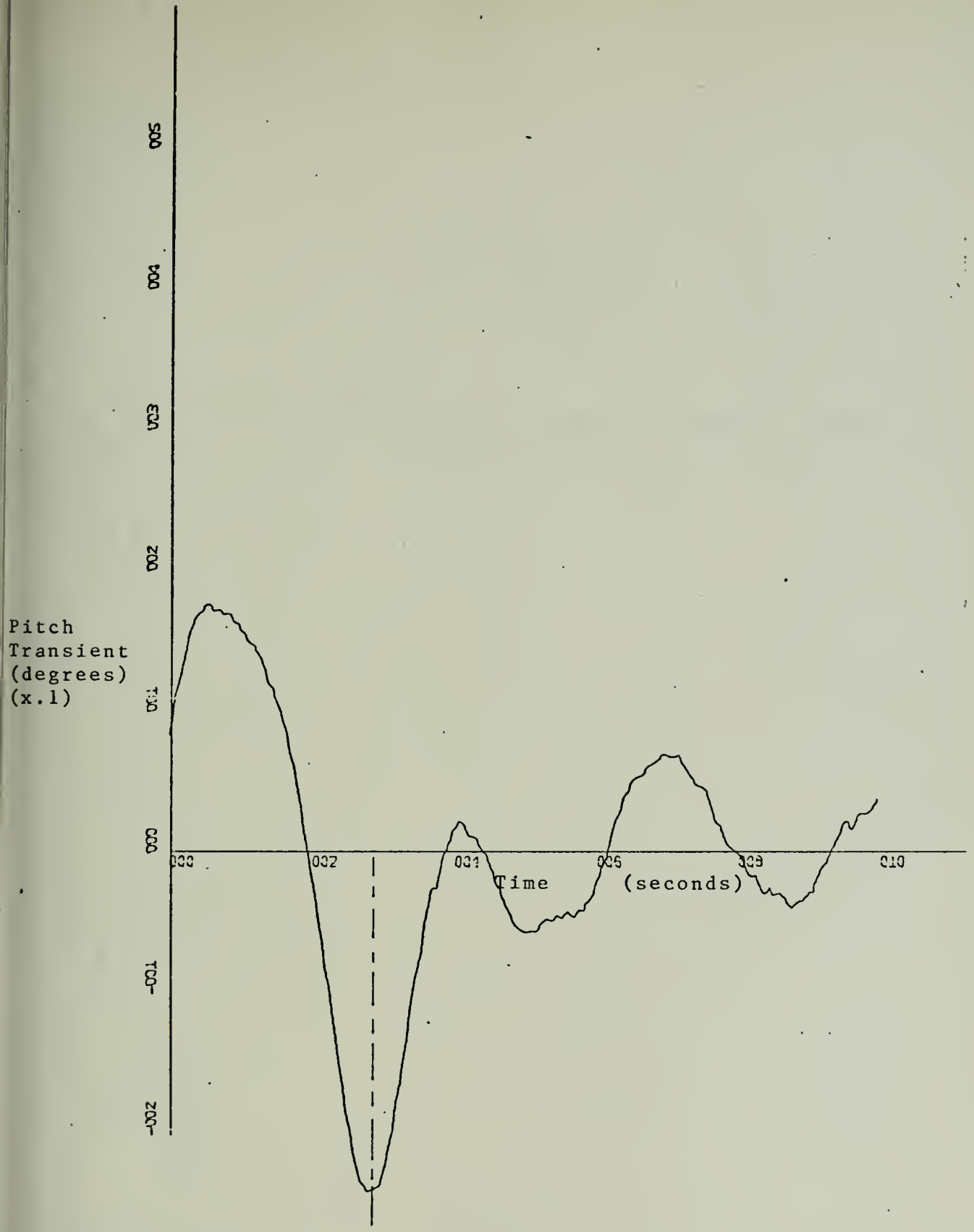


FIGURE 23

PITCH TRANSIENT VERSES TIME, VELOCITY 15.93 KNOTS

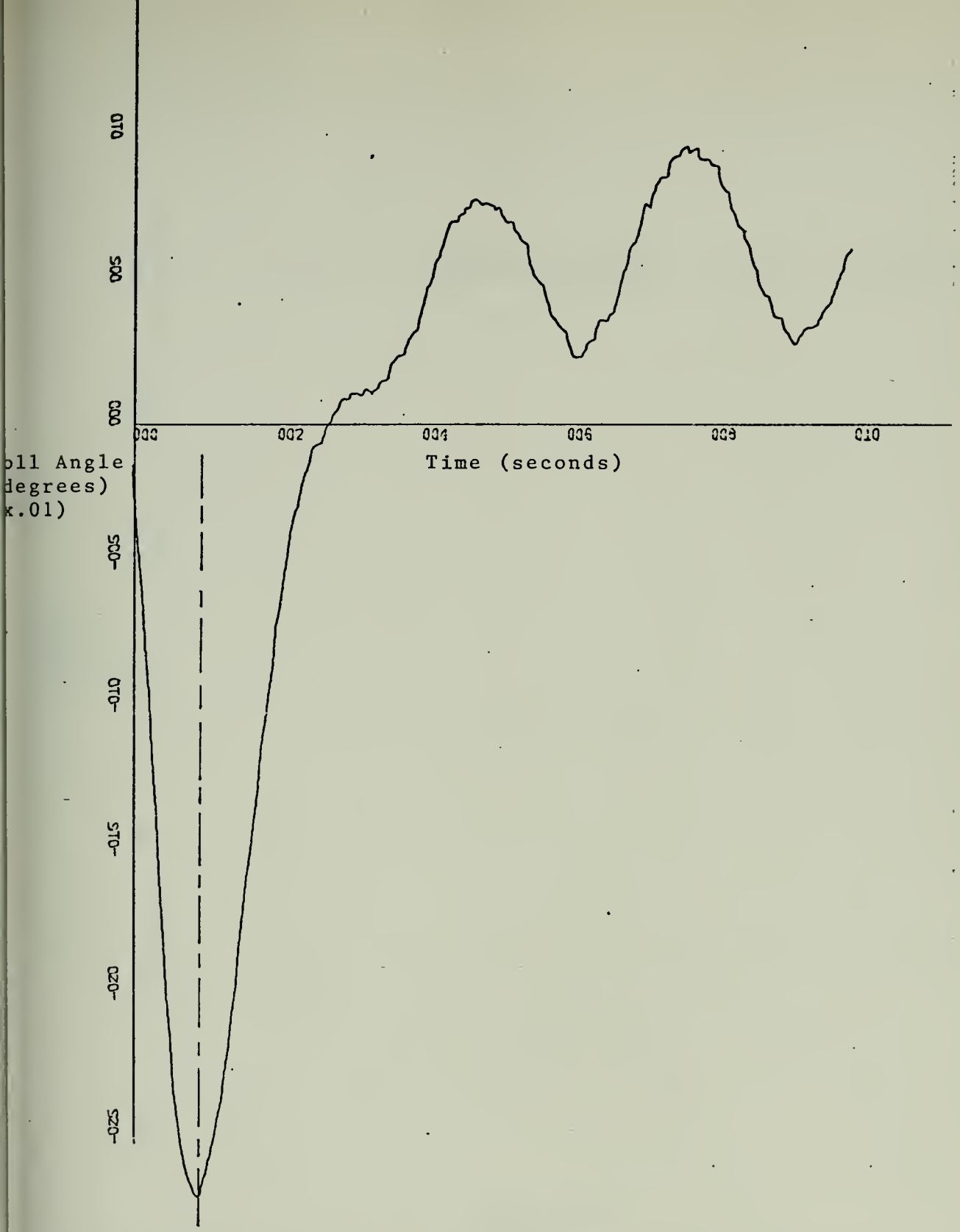


FIGURE 24

ROLL TRANSIENT VERSES TIME, VELOCITY 15.93 KNOTS

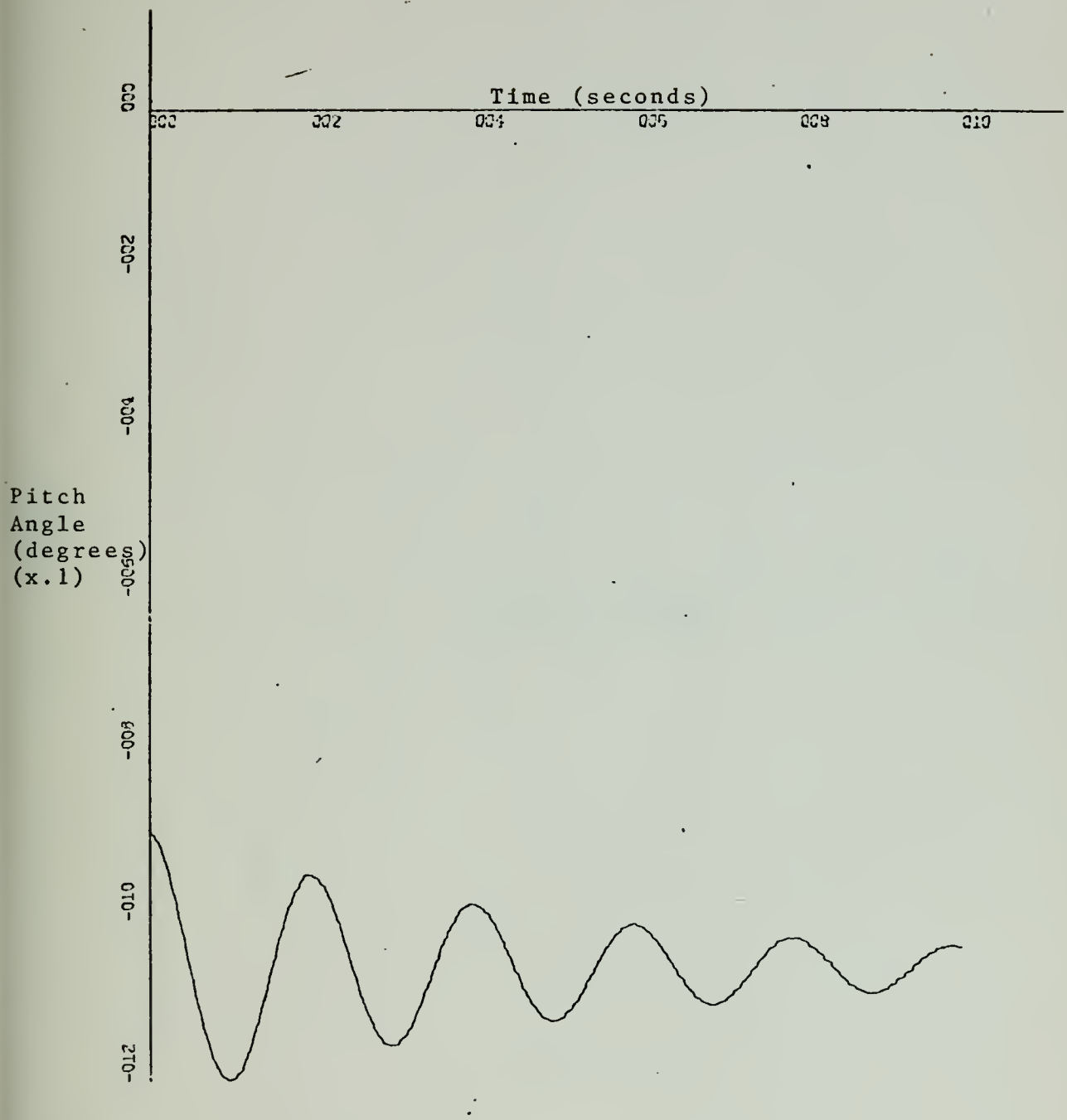


FIGURE 25

COMPUTER SIMULATION PITCH ANGLE VERSES TIME, 15.93 KNOTS
ORIGINAL XR-3

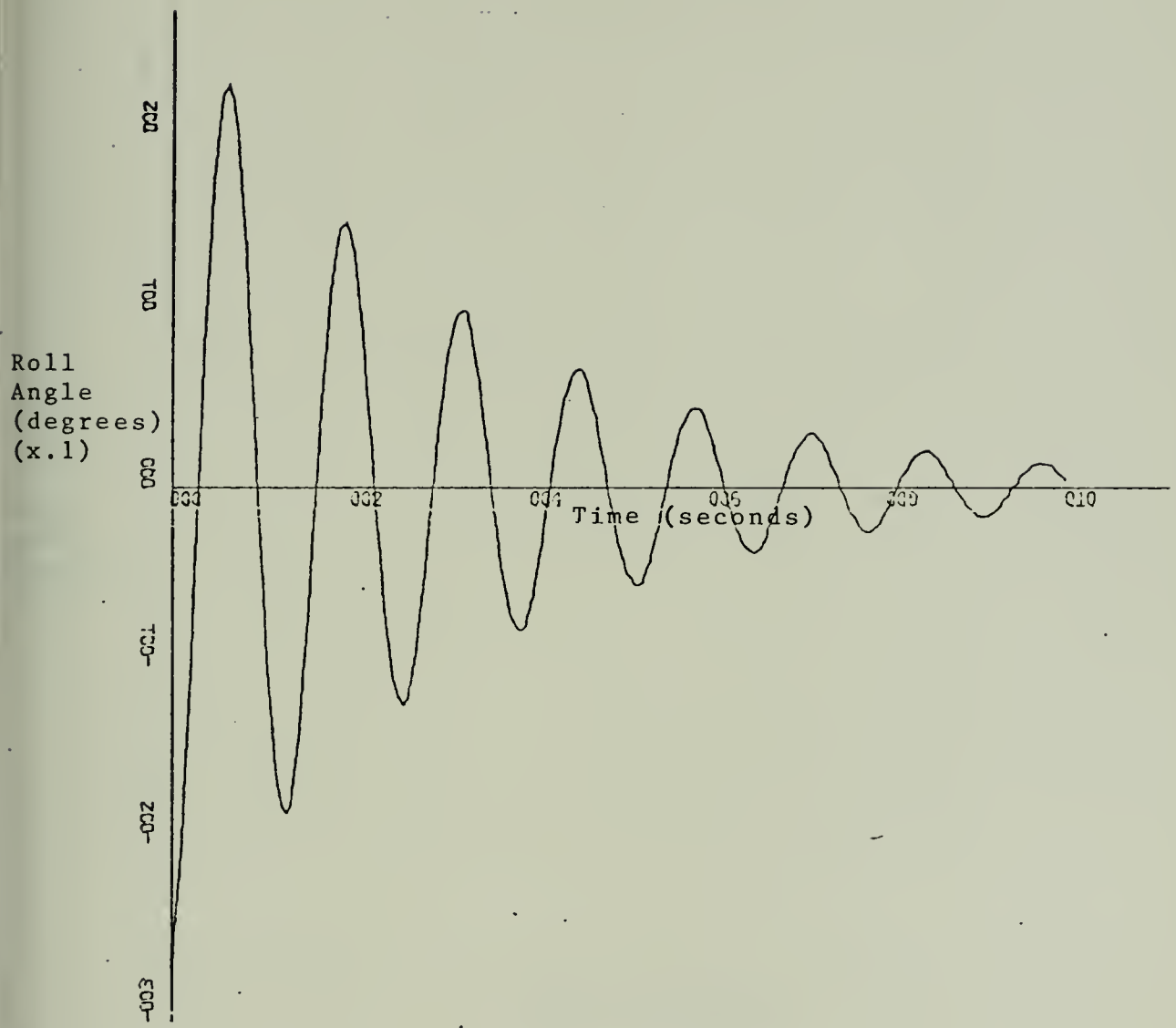


FIGURE 26

COMPUTER SIMULATION ROLL ANGLE VERSES TIME, 15.93 KNOTS
ORIGINAL XR-3

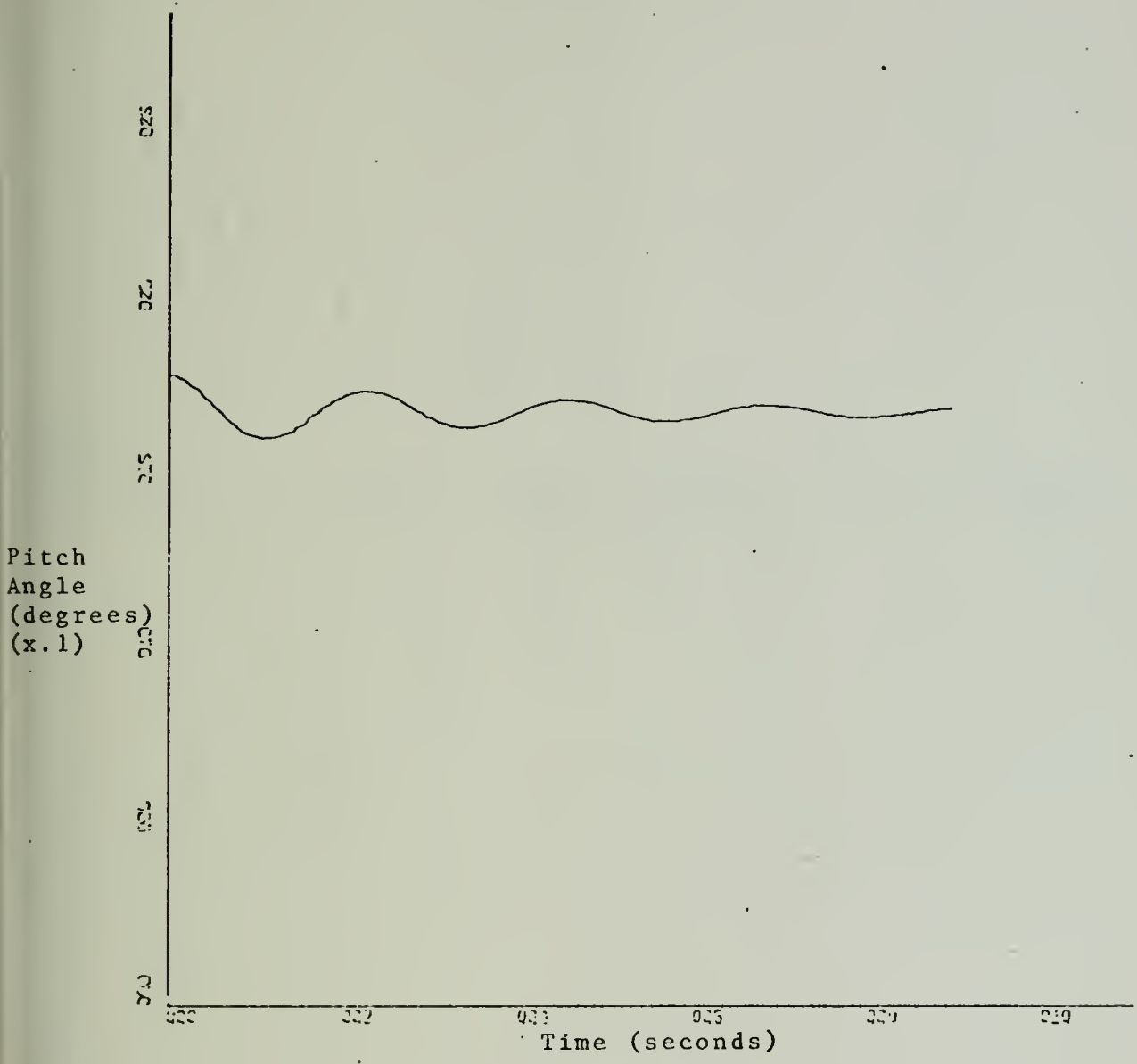


FIGURE 27

COMPUTER SIMULATION PITCH ANGLE VERSES TIME, 15.93 KNOTS
NEW XR-3

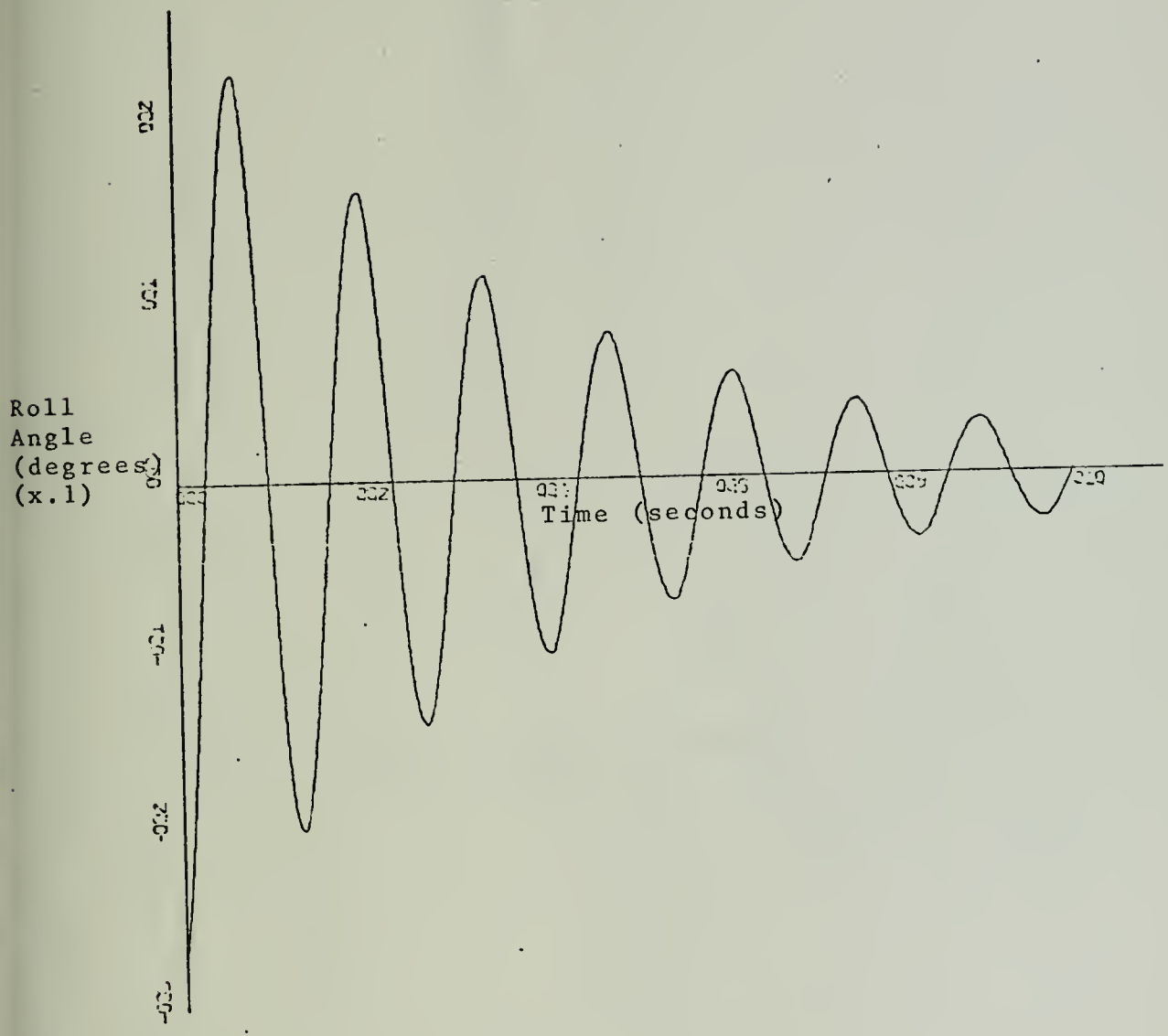


FIGURE 28

COMPUTER SIMULATION ROLL ANGLE VERSES TIME, 15.93 KNOTS
NEW XR-3

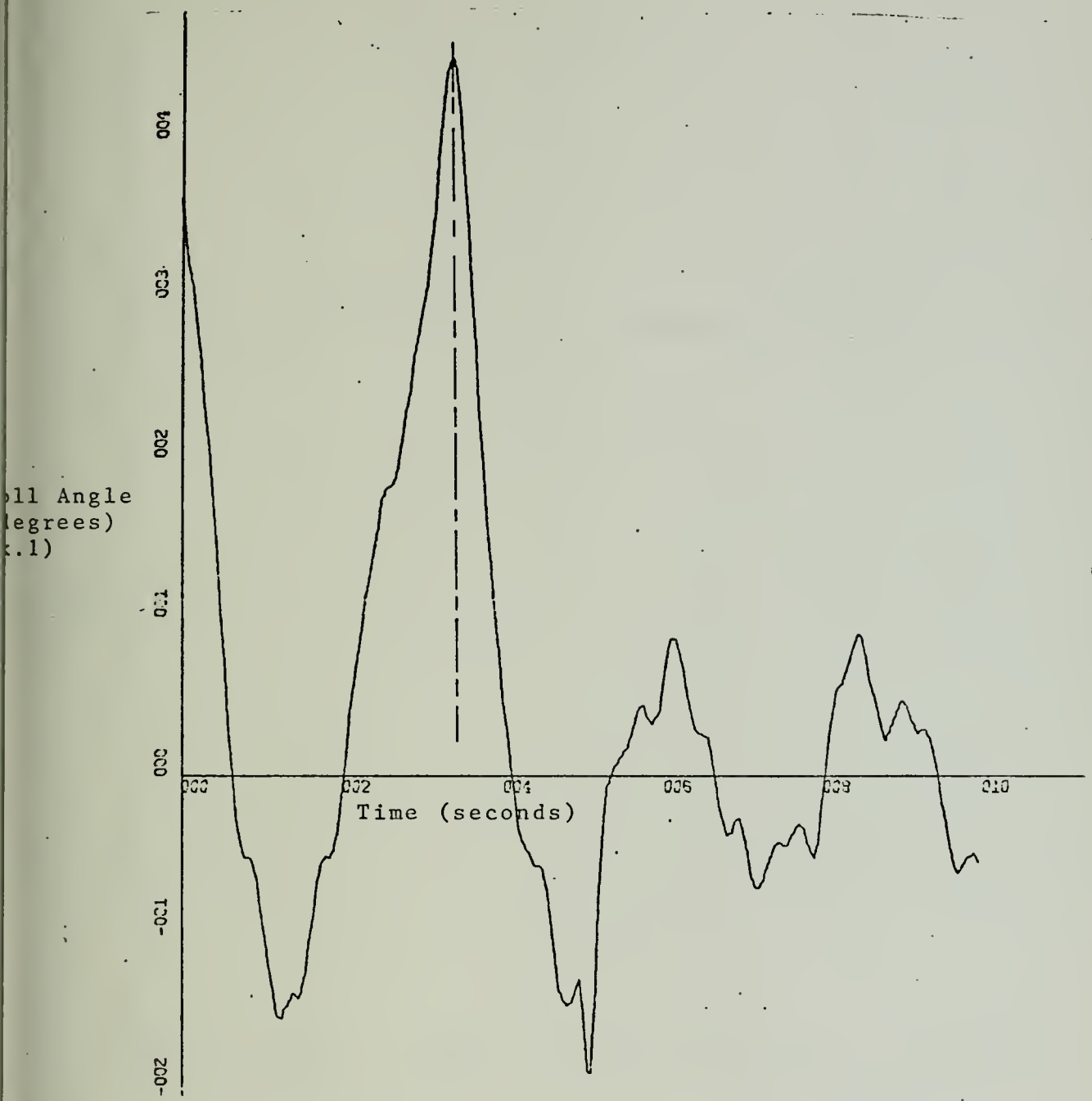


FIGURE 29

ROLL TRANSIENT VERSES TIME, VELOCITY 19.45 KNOTS

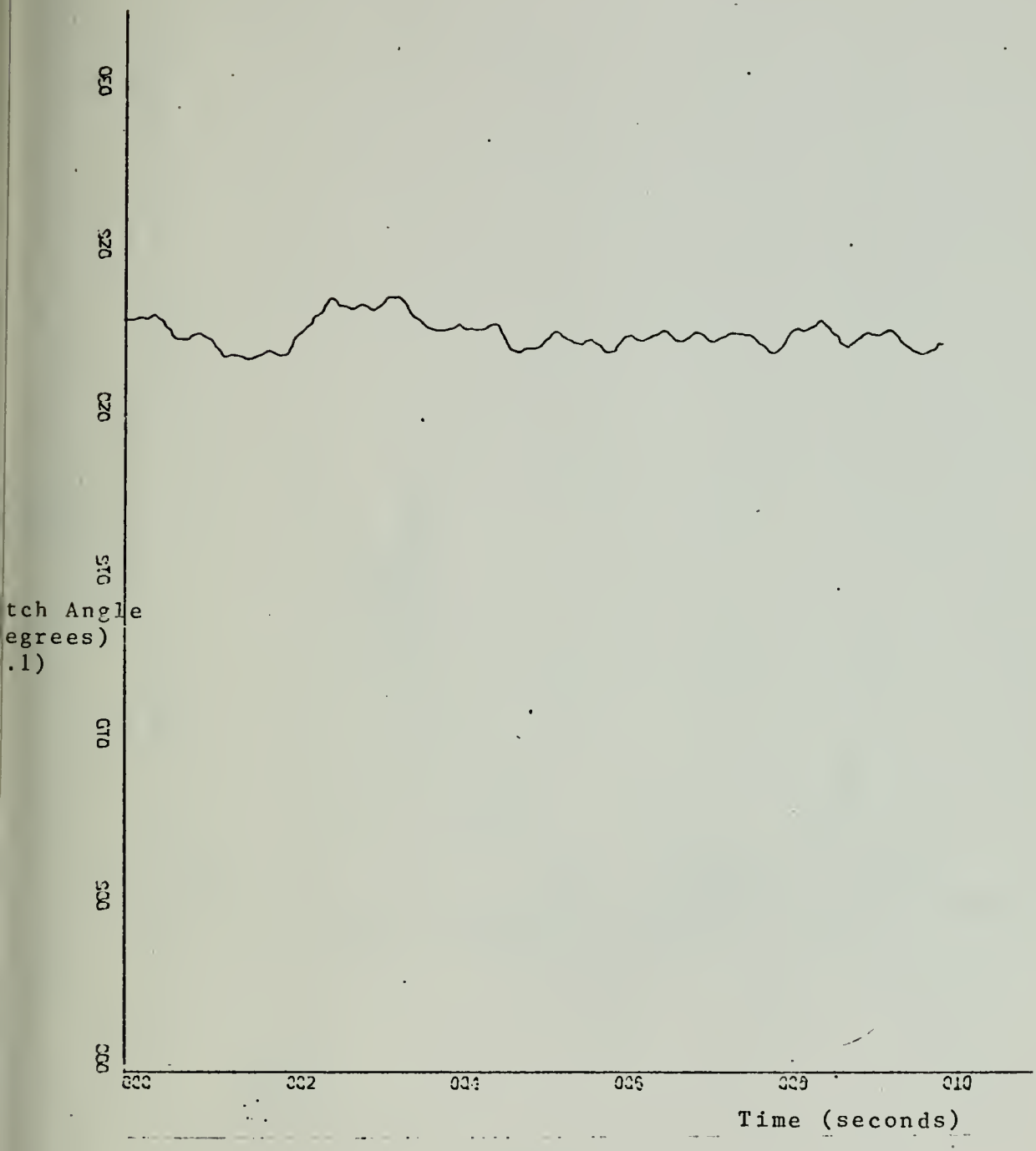


FIGURE 30

PITCH VERSES TIME, VELOCITY 19.45 KNOTS

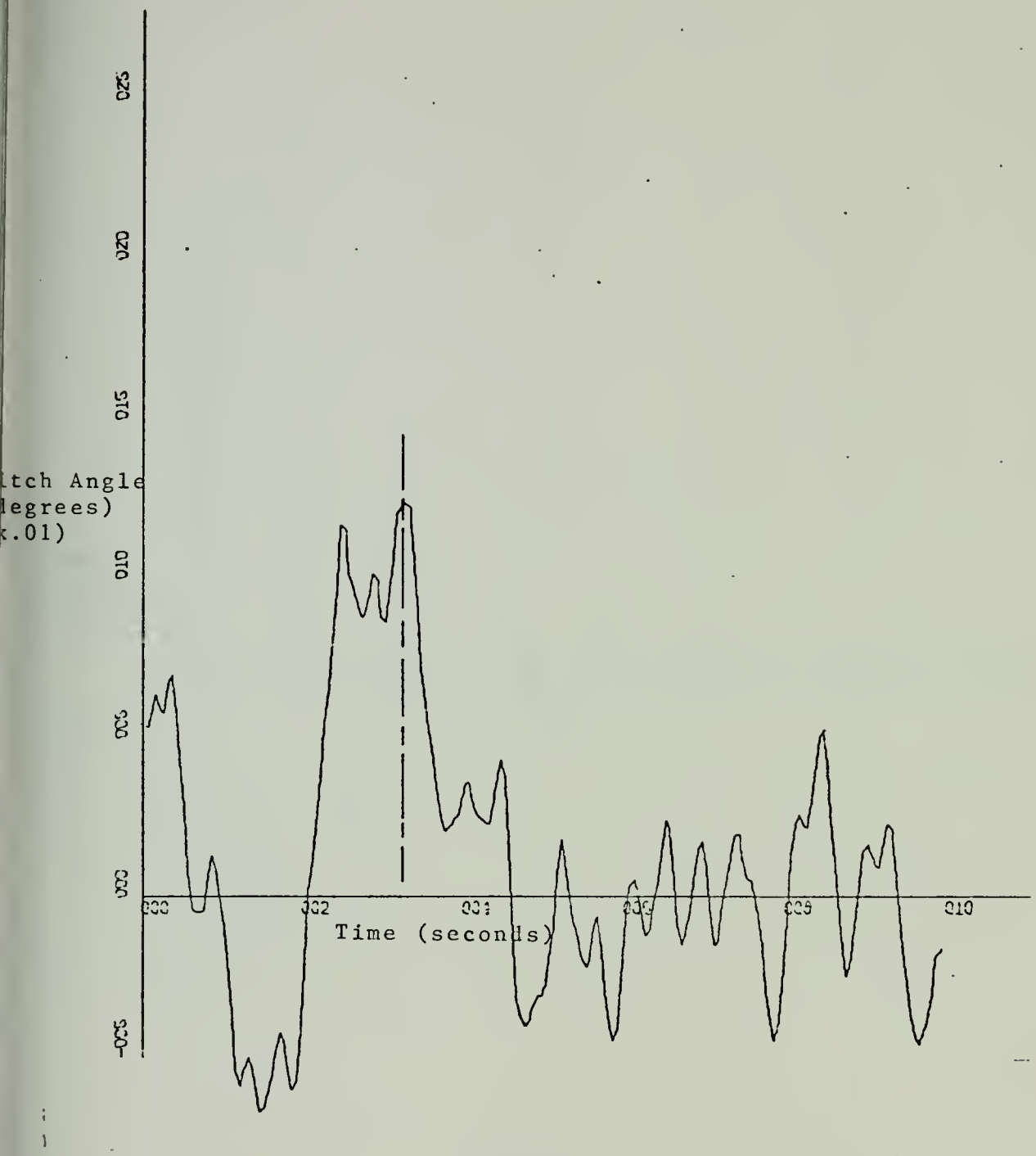


FIGURE 31

PITCH TRANSIENT VERSES TIME, VELOCITY 19.45 KNOTS

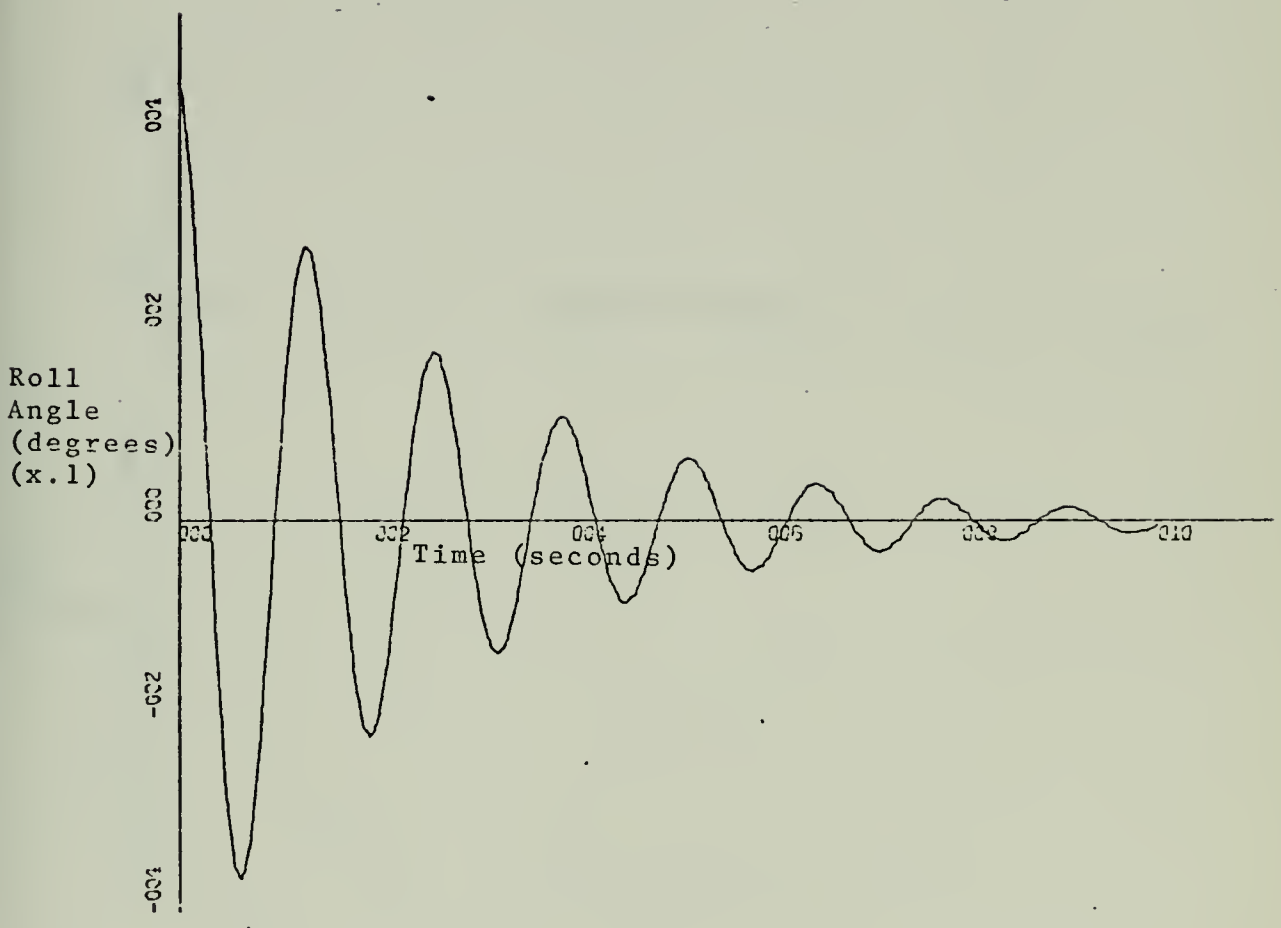


FIGURE 32

COMPUTER SIMULATION ROLL ANGLE VERSES TIME, 19.45 KNOTS
ORIGINAL XR-3

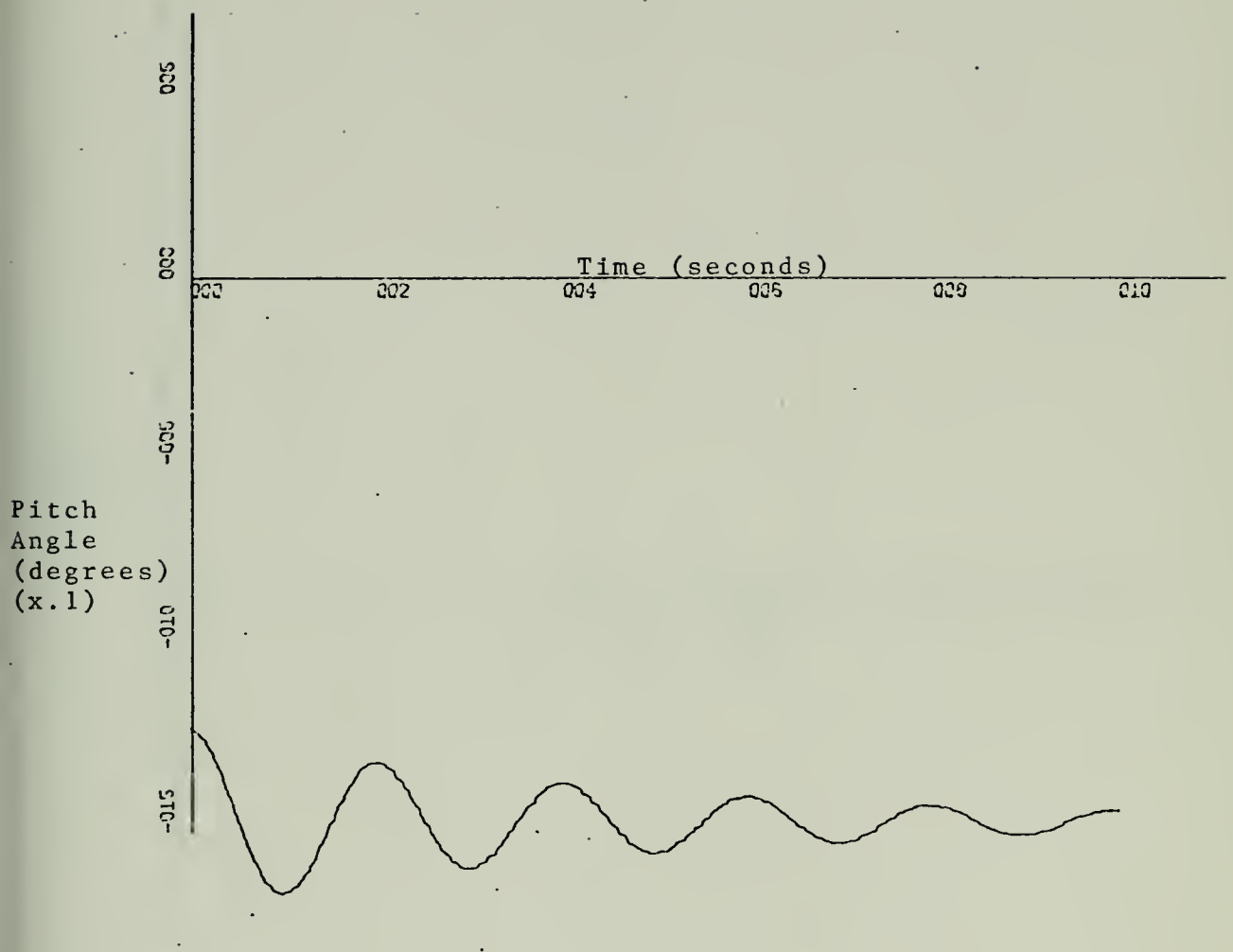


FIGURE 33

COMPUTER SIMULATION PITCH ANGLE VERSES TIME, 19.45 KNOTS
ORIGINAL XR-3

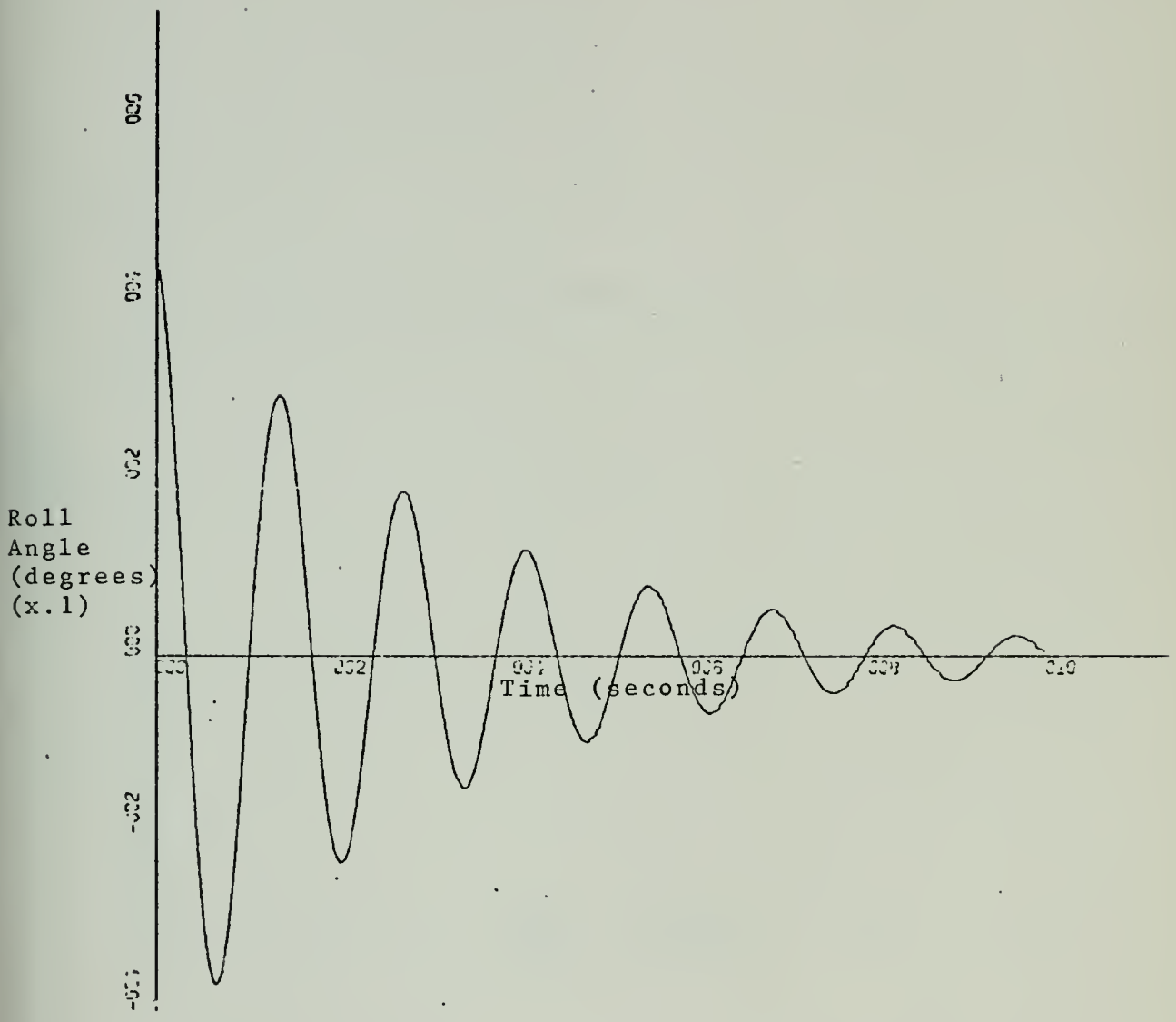


FIGURE 34

COMPUTER SIMULATION ROLL ANGLE VERSES TIME, 19.45 KNOTS
NEW XR-3

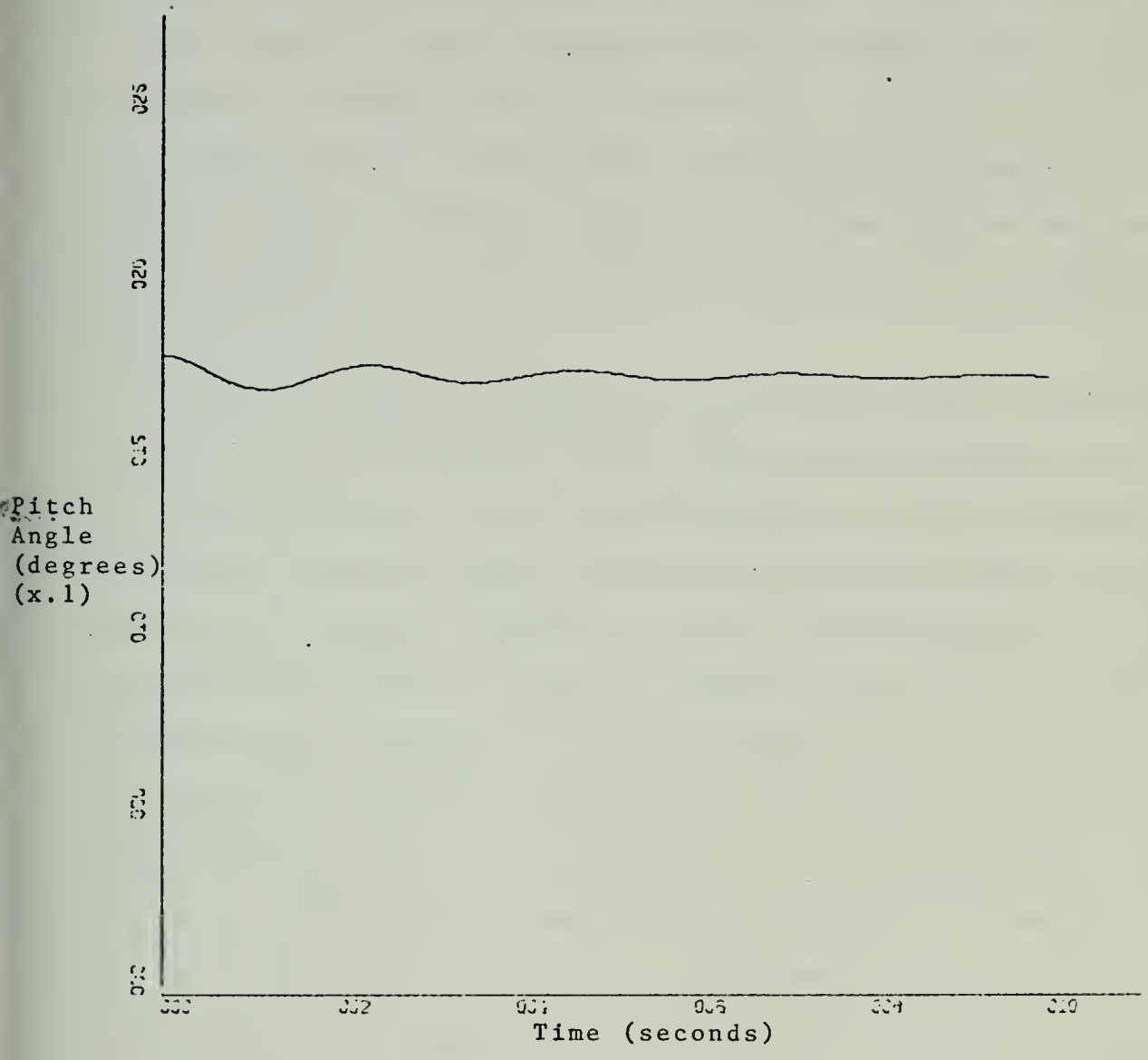


FIGURE 35

COMPUTER SIMULATION PITCH ANGLE VERSES TIME, 19.45 KNOTS NEW XR-3

same initial conditions that they were during the 19.45 knot run except for the offset. In the case of the new model this raised the bow approximately six inches and since the steady state condition gave the bow a depth of about three inches with the positive steady state pitch angle this caused air gaps to appear beneath the bow seal. In the case of the old model where the steady state pitch angle was negative no air gaps were created. Figures 36 through 38 present the original model's response and Figures 39 through 41 present the new model's response.

As can be seen in Figure 40, the air gap on the new model caused wide fluctuations in the plenum pressure during the first half-second. This loss of pressure permitted the boat to rapidly sink as shown in Figure 41 until the plenum pressure built up. When the air gaps closed and the boat continued to settle the plenum pressure rapidly rose as the plenum volume decreased. The boat exponentially returned to steady state draft levels as the pitch motion shown in Figure 39 died down. The pitch motion of the new model shows the effect of the new seals. The downward movement of the bow as seen in Figure 39 is severely limited as the bow seal wetted length becomes greater and the effect of the rigid body analysis comes into play. The first negative overshoot is limited to 34 percent of the original effect. The initial decay time constant is 2.5 seconds and the pitch frequency is .63 Hz which because of the nonlinearity

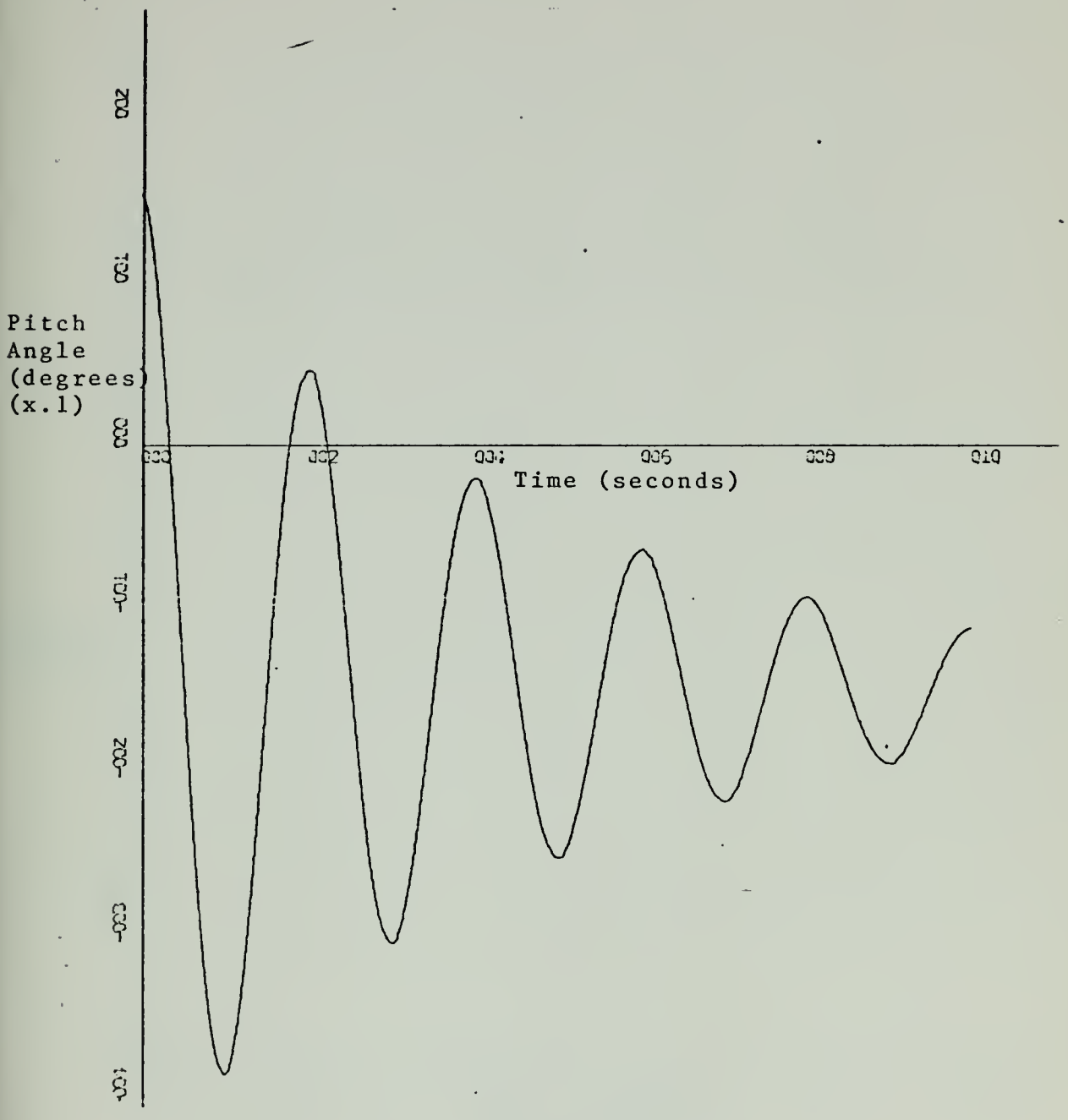


FIGURE 36

COMPUTER SIMULATION 3 DEGREE PITCH STEP RESPONSE, 19.45 KNOTS
ORIGINAL XR-3 PITCH VERSES TIME

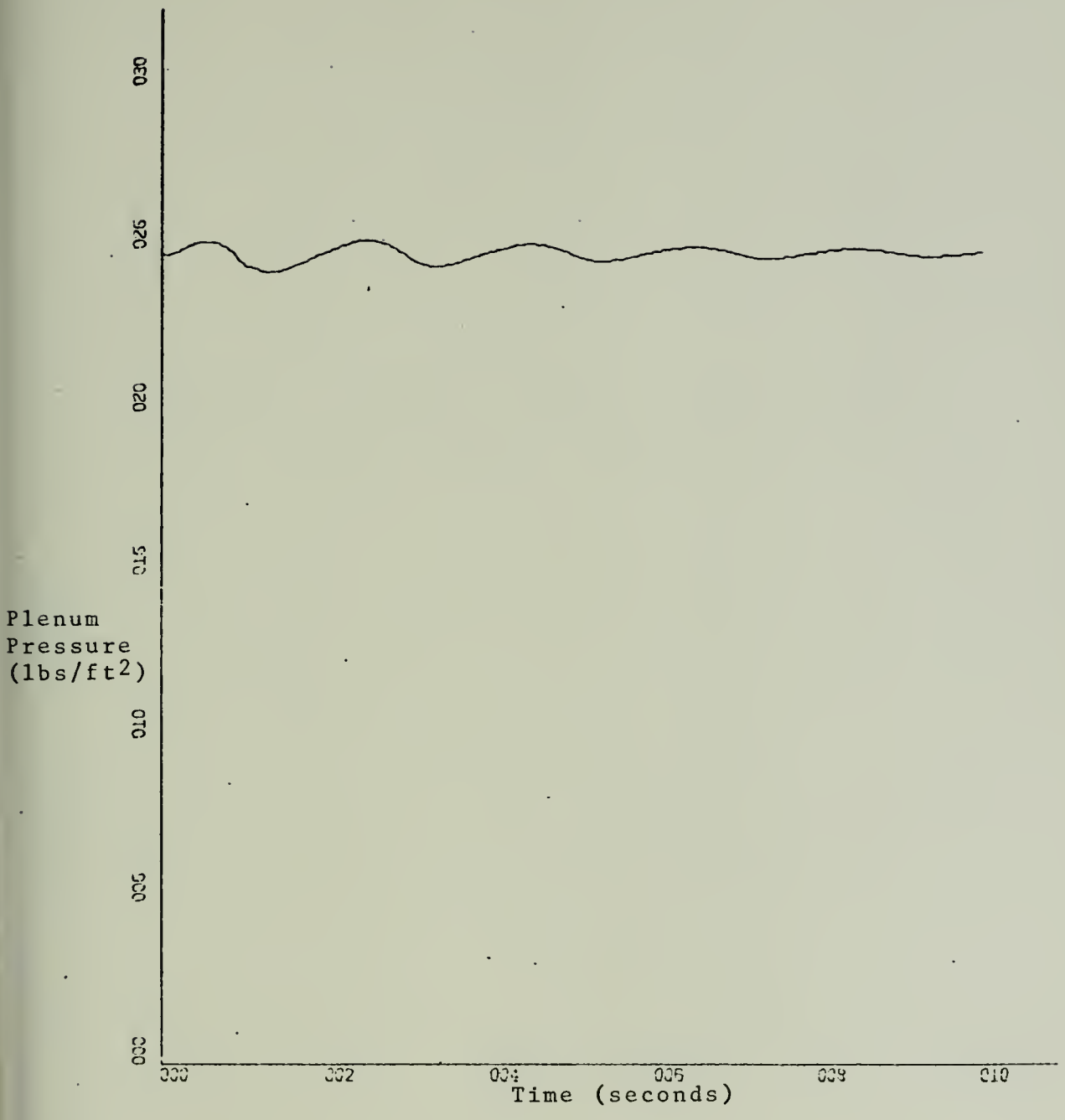


FIGURE 37

COMPUTER SIMULATION 3 DEGREE PITCH STEP RESPONSE, 19.45 KNOTS
ORIGINAL XR-3 PLENUM PRESSURE VERSES TIME

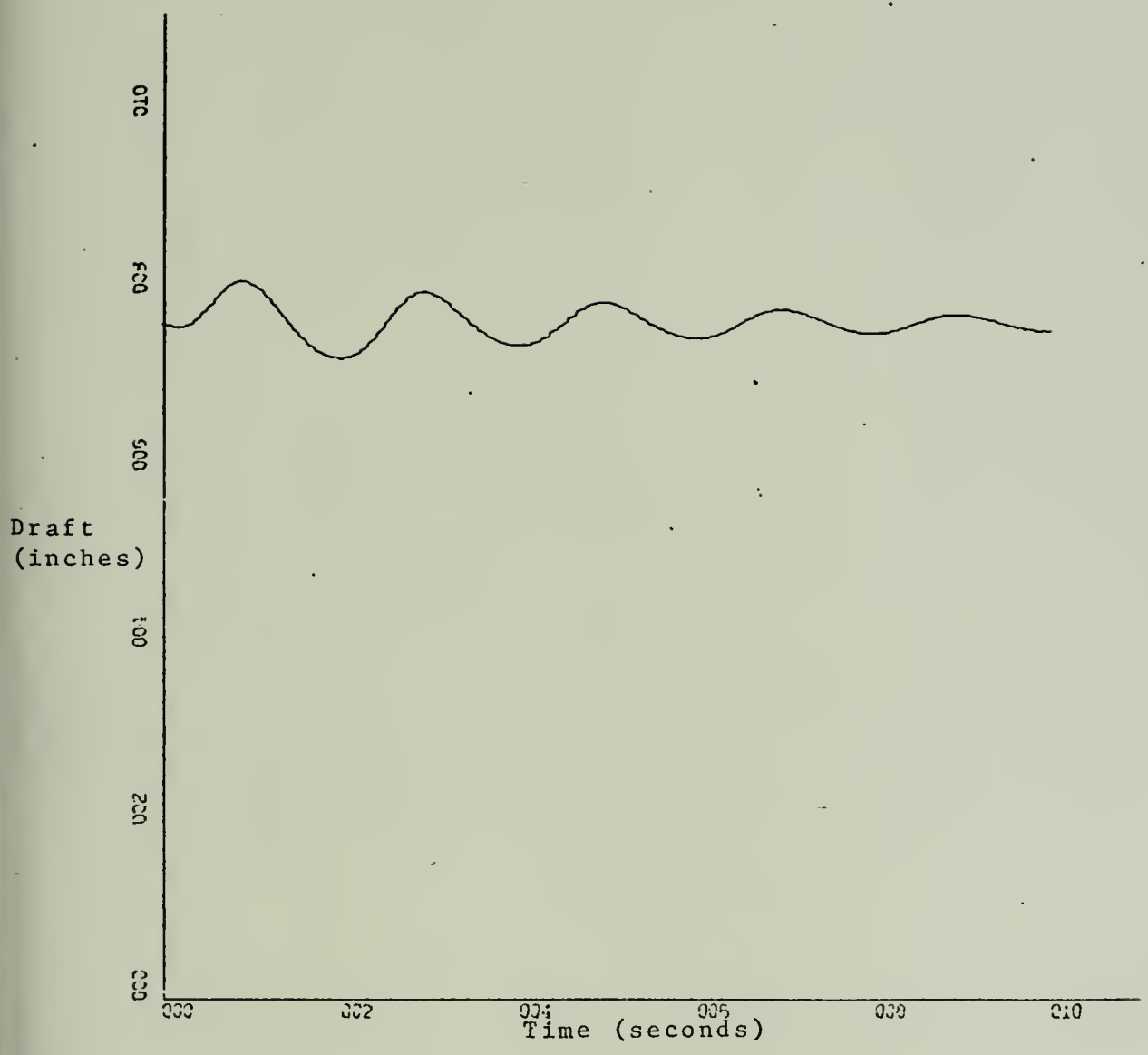


FIGURE 38

COMPUTER SIMULATION 3 DEGREE PITCH STEP RESPONSE, 19.45 KNOTS
ORIGINAL XR-3 DRAFT AT C.G. VERSES TIME

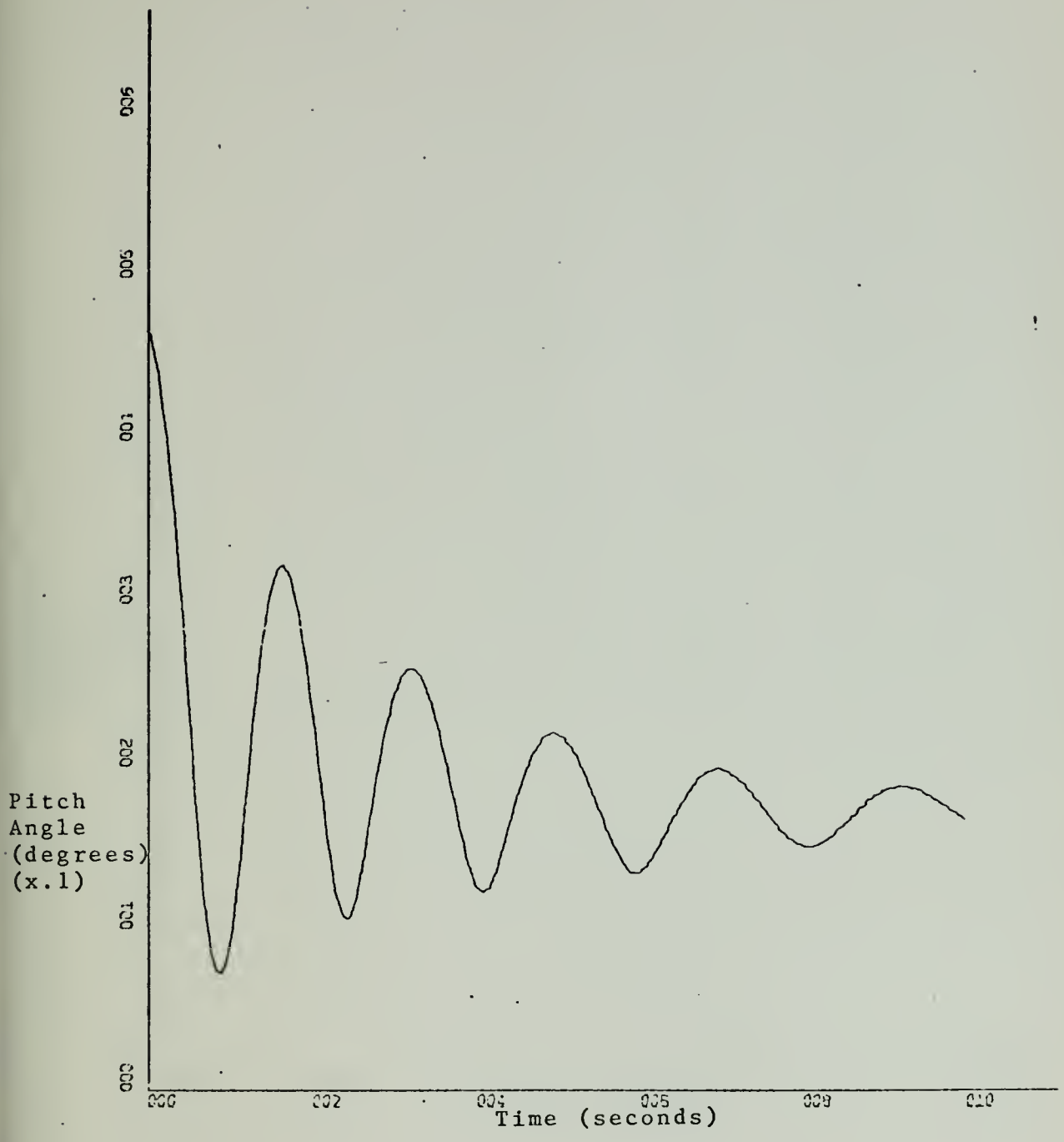


FIGURE 39

COMPUTER SIMULATION 3 DEGREE PITCH STEP RESPONSE, 19.45 KNOTS
NEW XR-3 PITCH VERSES TIME

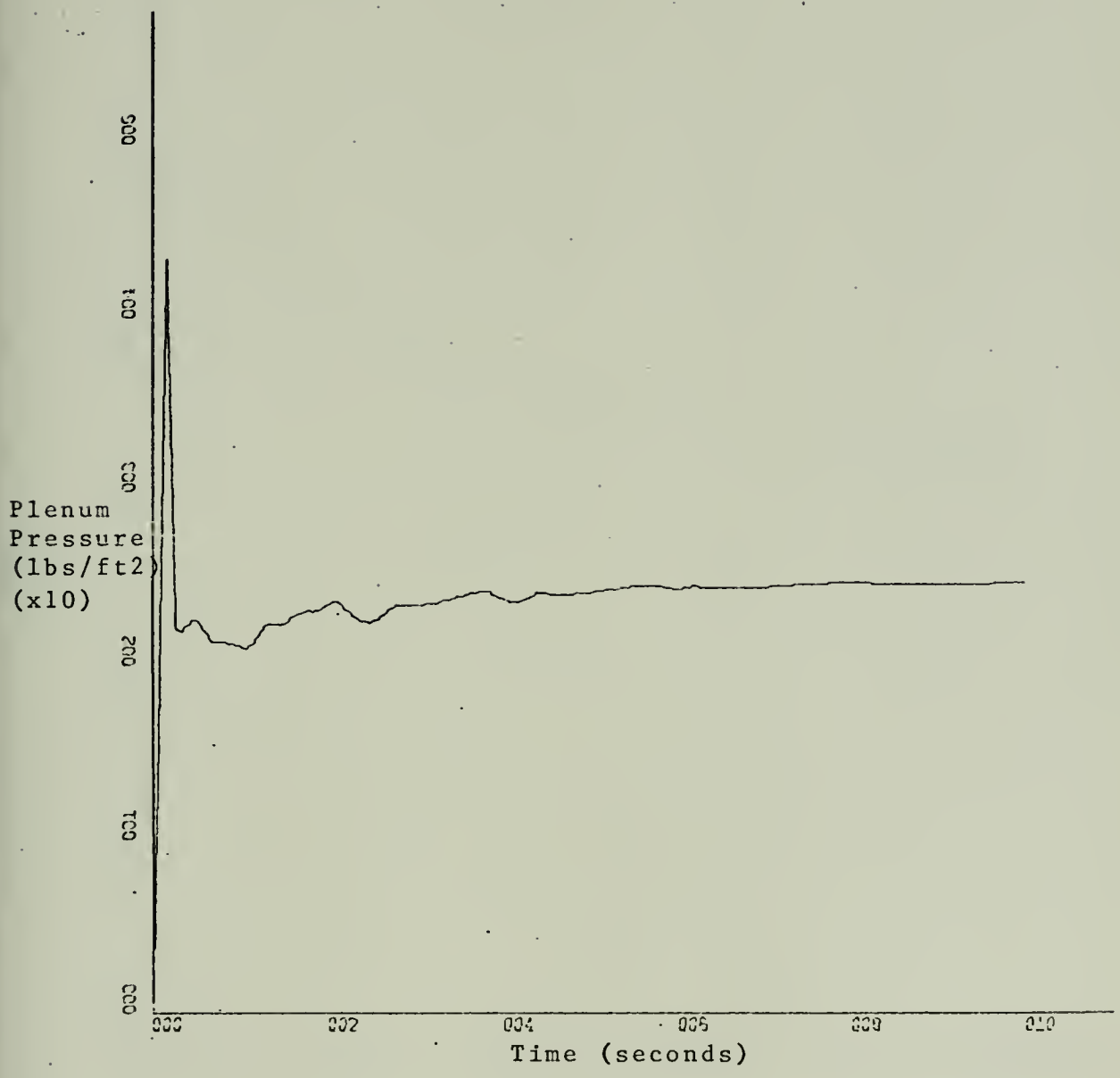


FIGURE 40

COMPUTER SIMULATION 3 DEGREE PITCH STEP RESPONSE, 19.45 KNOTS NEW XR-3 PLENUM PRESSURE VERSES TIME.

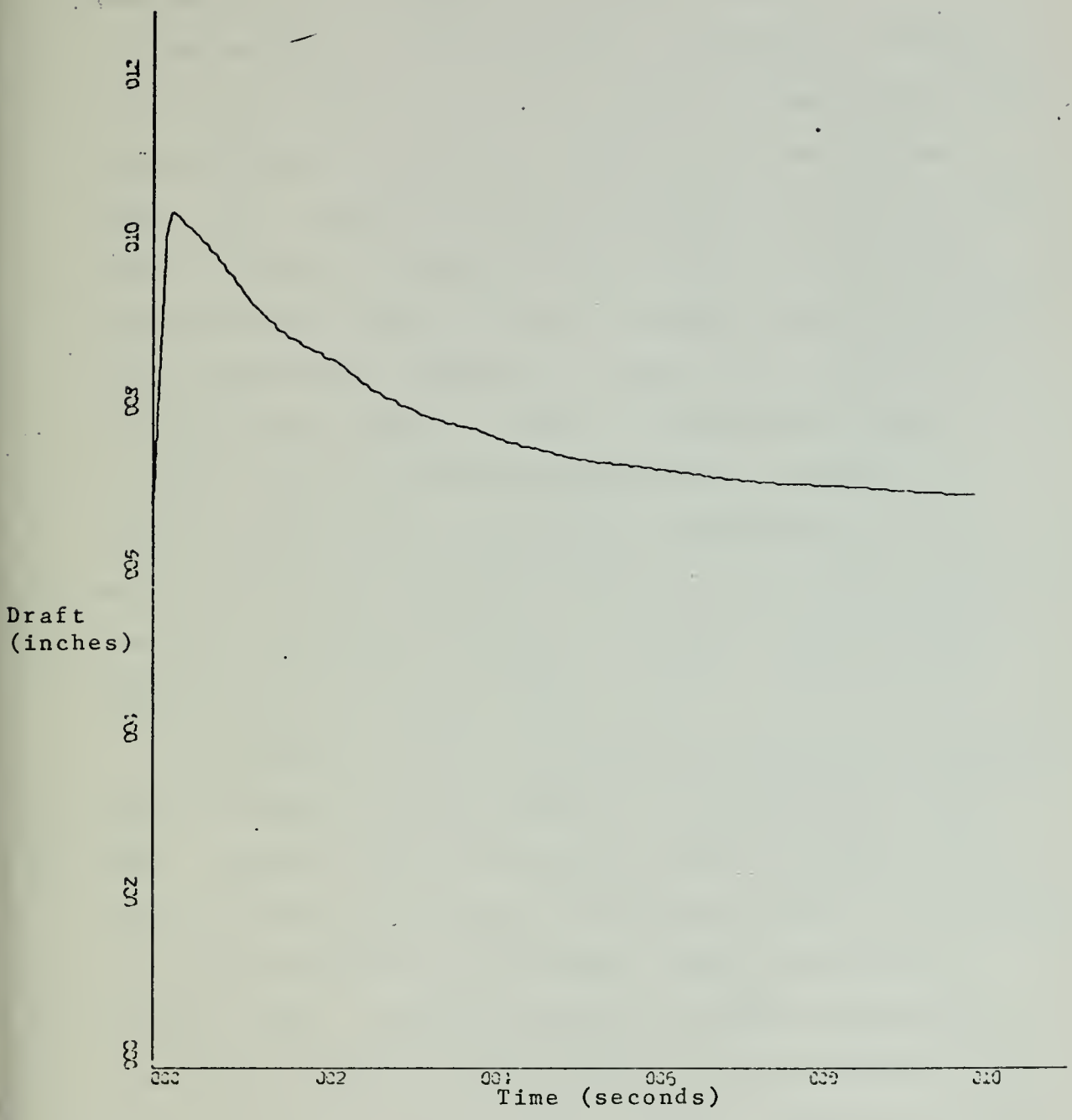


FIGURE 41

COMPUTER SIMULATION 3 DEGREE PITCH STEP RESPONSE, 19.45 KNOTS
NEW XR-3 DRAFT AT C.G. VERSES TIME

of the bow and stern seal models changes to a frequency of .42 Hz at the end of ten seconds. The time constant has lengthened to 4.3 seconds in the same period.

The behavior of the old model is different. Because of the high capacity of the fan maps the damping effect of plenum pressure is minimal. The draft movement shown in Figure 38 is therefore highly underdamped whereas the draft motion for the new model did not display any oscillatory tendencies (see Figure 41) and displayed exponential decay type response when returning to steady state conditions. In pitch motion shown in Figure 36 the original model displays a first overshoot magnitude of 78 percent of original offset. The frequency of oscillation is .5 Hz and the decay time constant is 4.78 seconds. Both the time constant and pitch oscillation frequency remain constant throughout the 10 second simulation.

To further evaluate the differences between the original and new models a second simulation run was made at 19.45 knots. This run was in ahead sea state 2 irregular seas. Figures 42 and 43 show that the plenum pressure fluctuations in the new model were 600 percent greater than in the original model. Whereas the plenum pressure varied from 5 to about 45 PSF in the new model the pressure only varied from about 21 to 27 PSF in the original. Draft fluctuations were about 300 percent greater in the new model than in the original (see Figures 44 and 45). Pitch angle fluctuations were comparable in both models (Figures 46 and 47).

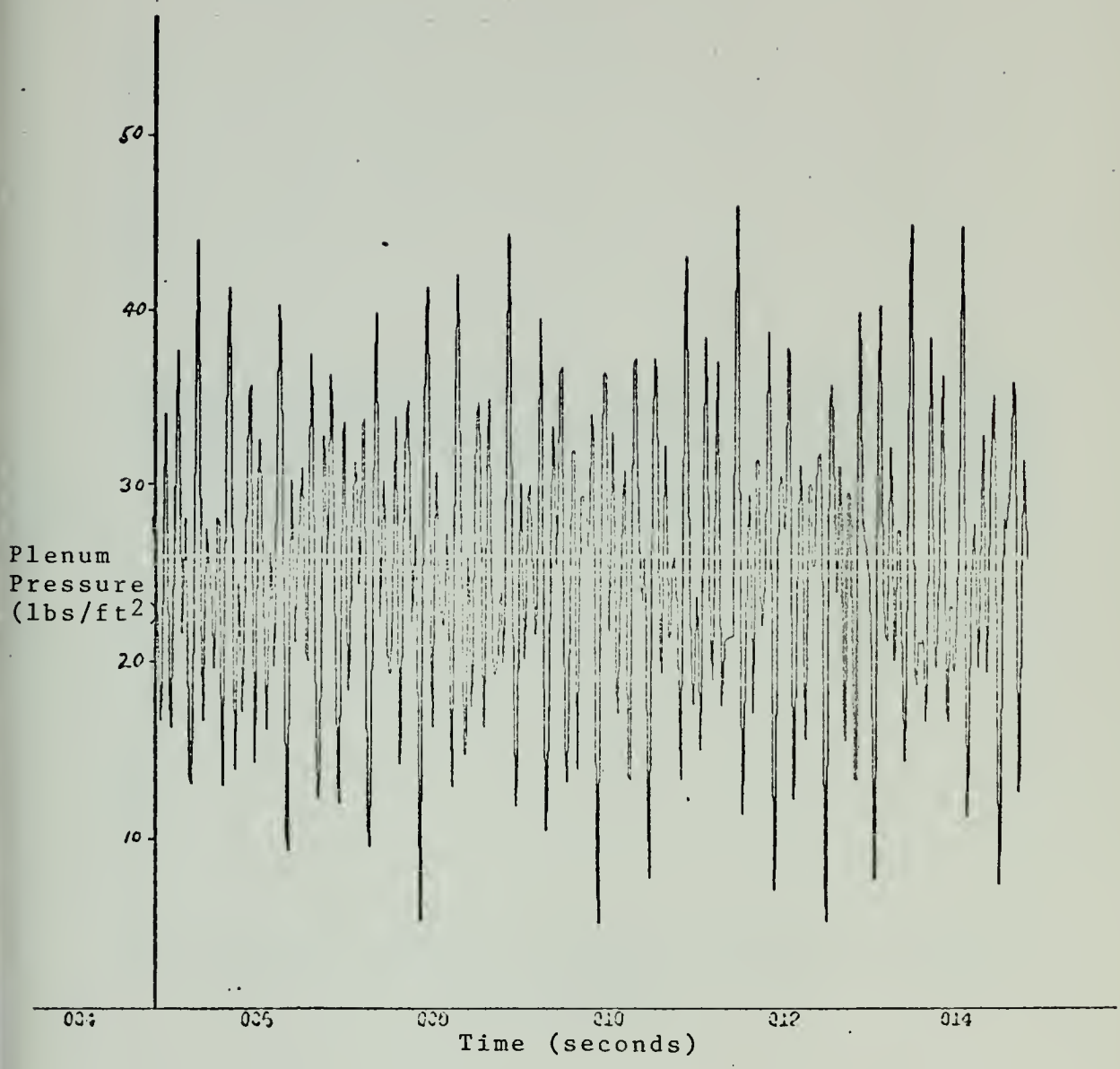


FIGURE 42

COMPUTER SIMULATION PLENUM PRESSURE VERSES TIME, 19.45 KNOTS NEW XR-3, SEA STATE 2

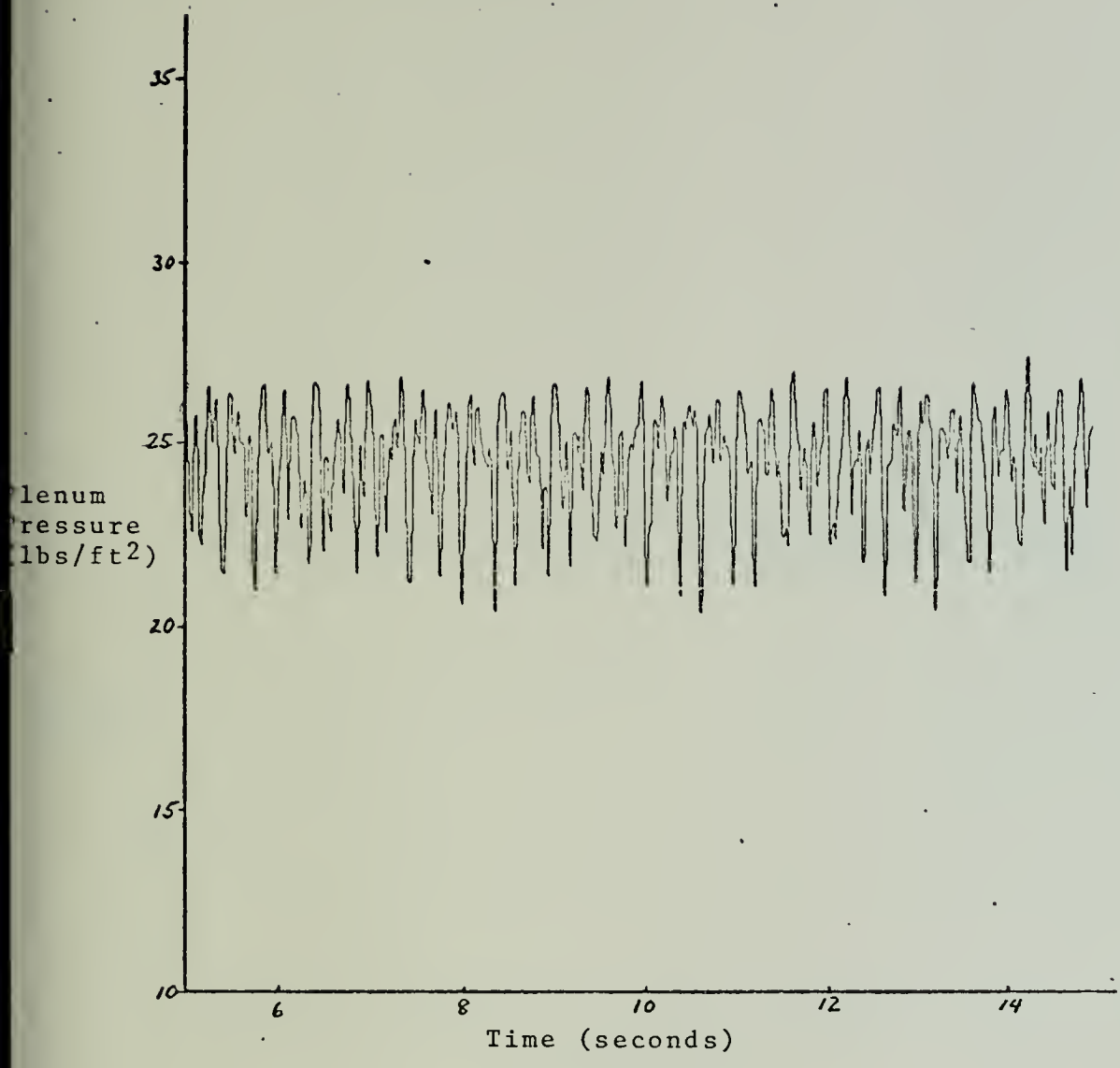


FIGURE 43

COMPUTER SIMULATION PLENUM PRESSURE VERSES TIME, 19.45 KNOTS ORIGINAL XR-3, SEA STATE 2

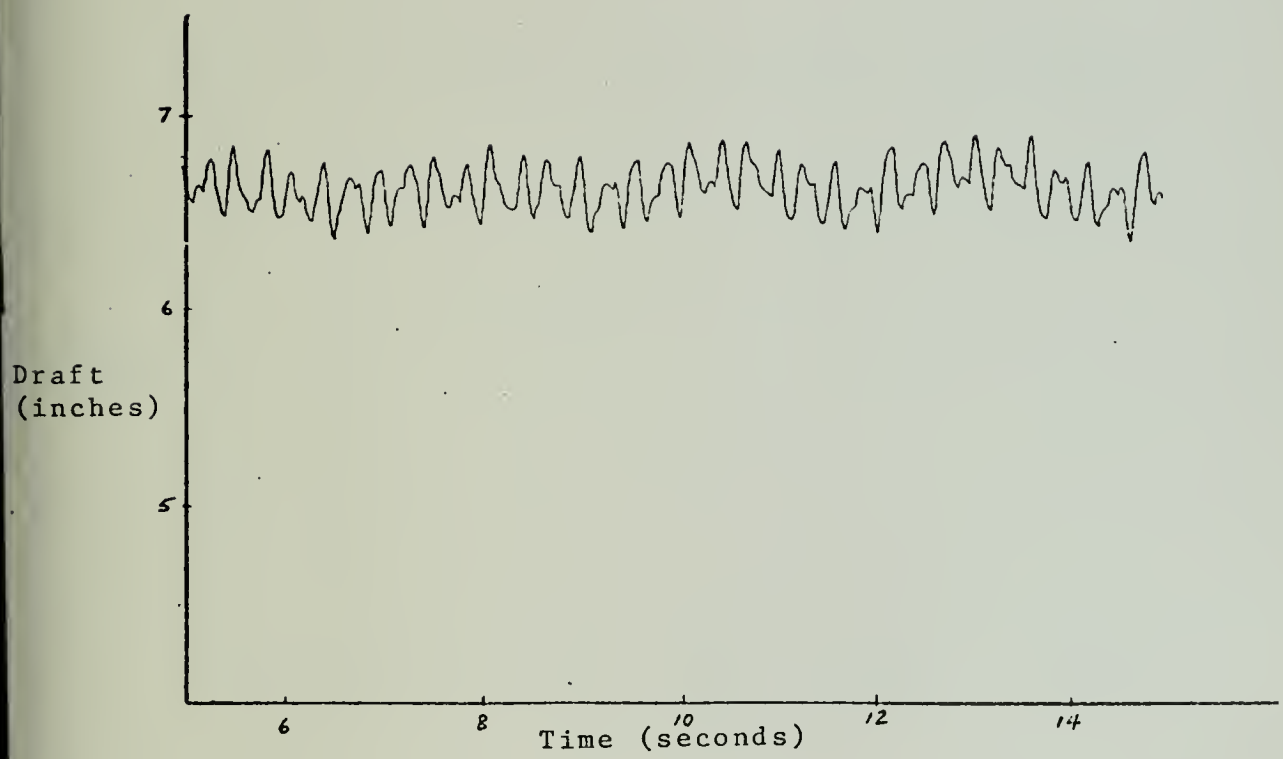


FIGURE 44

COMPUTER SIMULATION DRAFT AT C.G. VERSES TIME, 19.45 KNOTS
NEW XR-3, SEA STATE 2

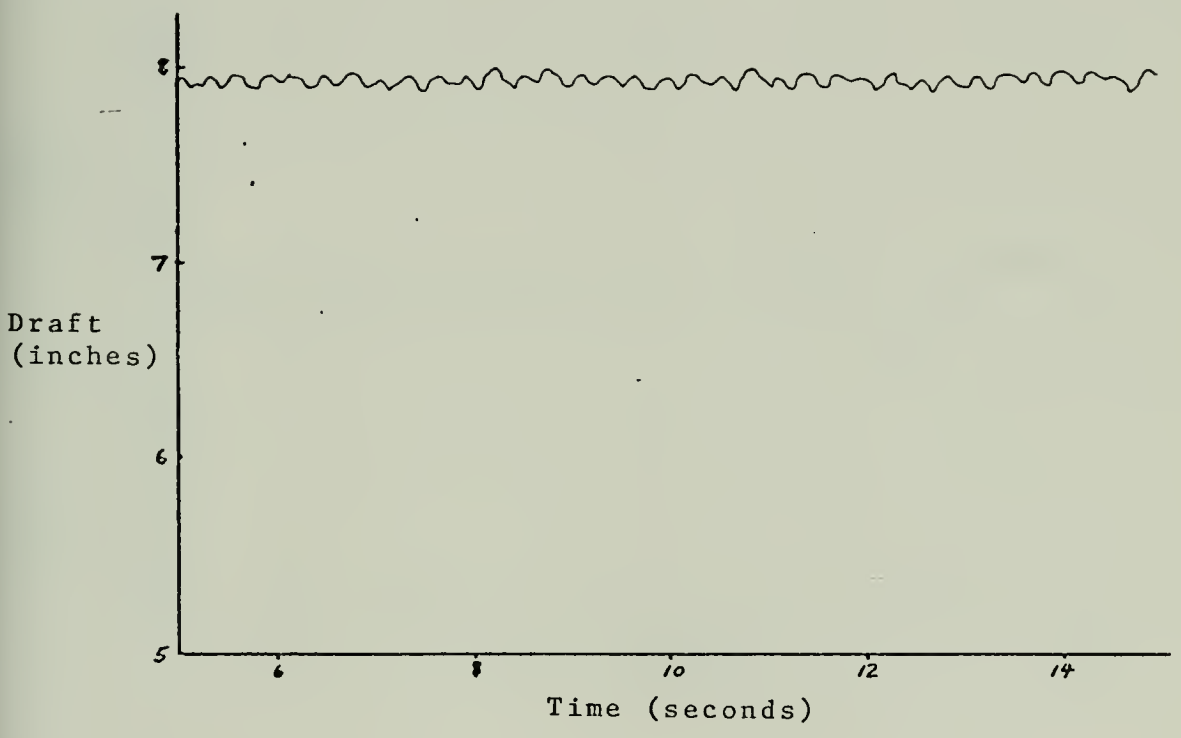


FIGURE 45

COMPUTER SIMULATION DRAFT AT C.G. VERSES TIME, 19.45 KNOTS
ORIGINAL XR-3, SEA STATE 2

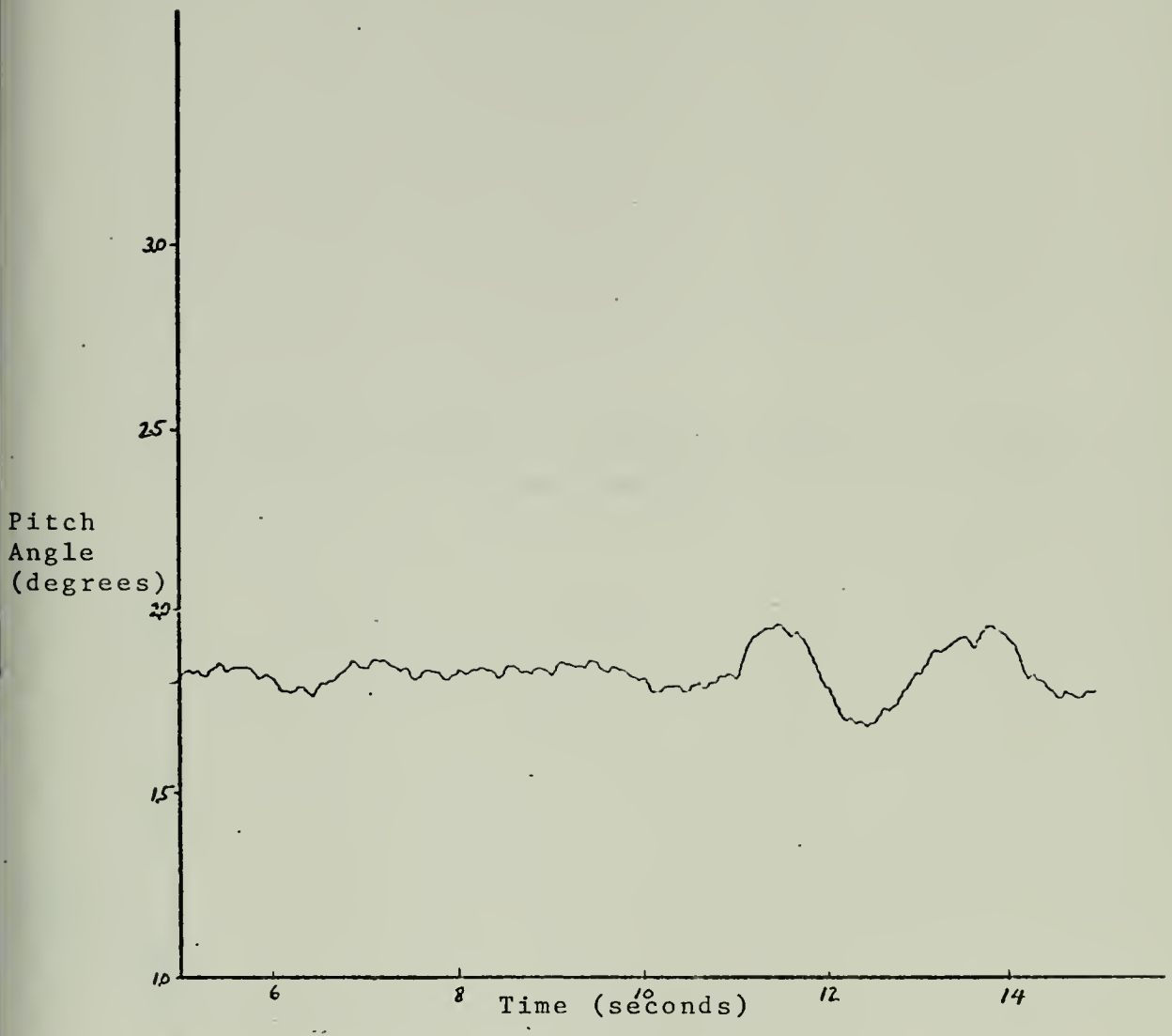


FIGURE 46

COMPUTER SIMULATION PITCH ANGLE VERSES TIME, 19.45 KNOTS NEW XR-3, SEA STATE 2

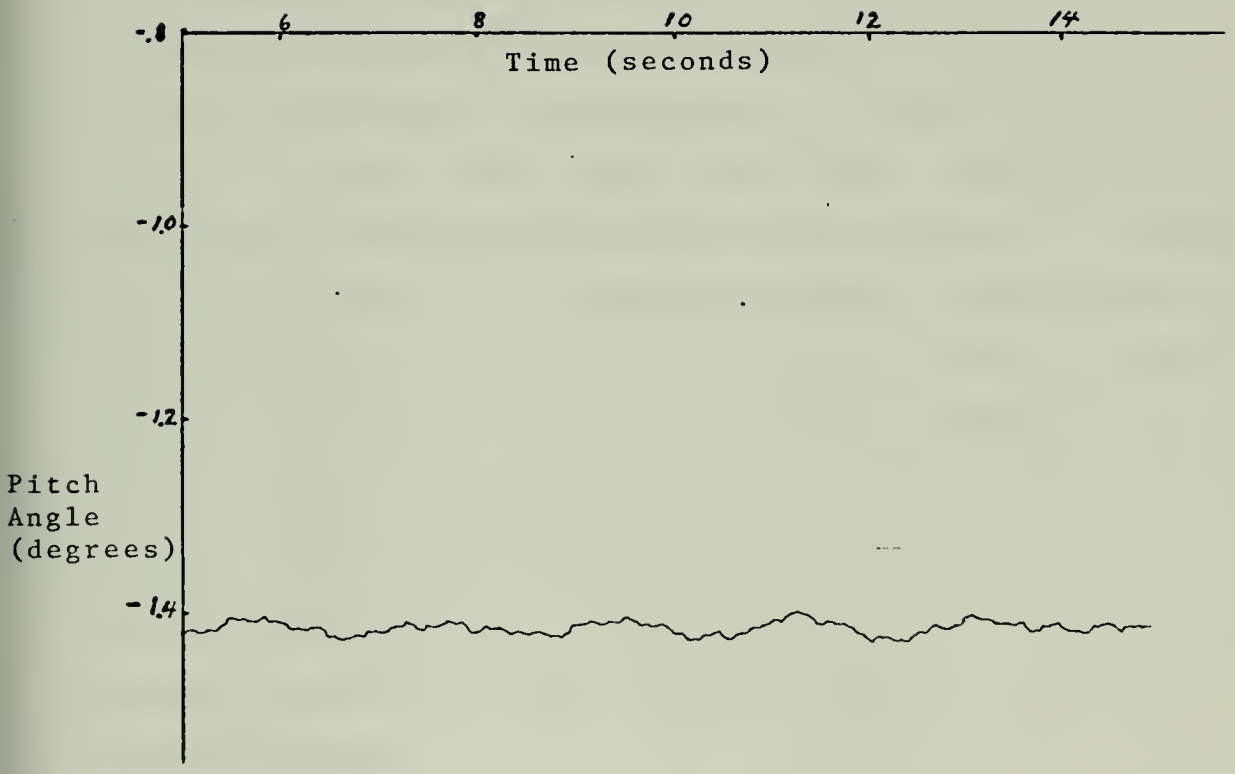


FIGURE 47

COMPUTER SIMULATION PITCH ANGLE VERSES TIME, 19.45 KNOTS
ORIGINAL XR-3, SEA STATE 2

V. CONCLUSIONS AND RECOMMENDATIONS

Making accurate measurements from the collected data was extremely difficult because of the high relative level of steady state oscillation present in both the pitch and roll motion. Signal noise coupled with the fact that the decay time constants and the periods of the oscillations were of the same general magnitude made accurate measurement of the decay time constants practically impossible.

Although accurate measurement of the time constants was not possible general observations could be made. It was clearly evident that the pitch and roll transients induced in the XR-3 test craft decayed very rapidly and not with the highly underdamped characteristics shown by the computer simulation models. The measured tape data confirmed the observations made aboard the XR-3 while conducting these runs that the craft come to steady state conditions with only one or two overshoots after the forcing action had ceased. Roll motion transients were normally completed in less than two cycles. Both the longitudinal and athwartships stability were highly speed dependent gaining stability as speed increased.

These observations were not based solely on "feel" but were made by sighting across the deck of the XR-3 and observing the motion of the deck edge relative to the shore line.

Simulation runs have shown that for large perturbations the transient response of the new model is quite different from the original. Since it was not possible to excite such large perturbations in the actual test craft it remains to be verified that the new bow and stern seal models more accurately predict the forces generated by the actual seals than does the original seal model.

The new seal fan maps are more accurate than the original since they are based on actual verified manufacturer's data. Leakage areas are now proportional to those of the actual craft.

The fact that the present computer models of the XR-3 both old and new do not appear to accurately represent the actual transient behavior of the XR-3 in pitch and roll opens many areas which should be investigated for possible errors. As both the pitch and roll transients appear to be in error the sidewall subroutine becomes a prime area of investigation as it contributes major components to both the roll and pitch force moments.

Figure 48 shows one area which should be explored and that is the area of hydrodynamic lift of the sidewalls. Figure 48 is a simplified drawing of the underside of the XR-3. The flat sections on the bottom of each sidewall are cross-hatched for clarity. At high velocity (20-25 knots) these areas become effective planing surfaces. In this program the lift of the sidewall sections due to planing does not appear to take

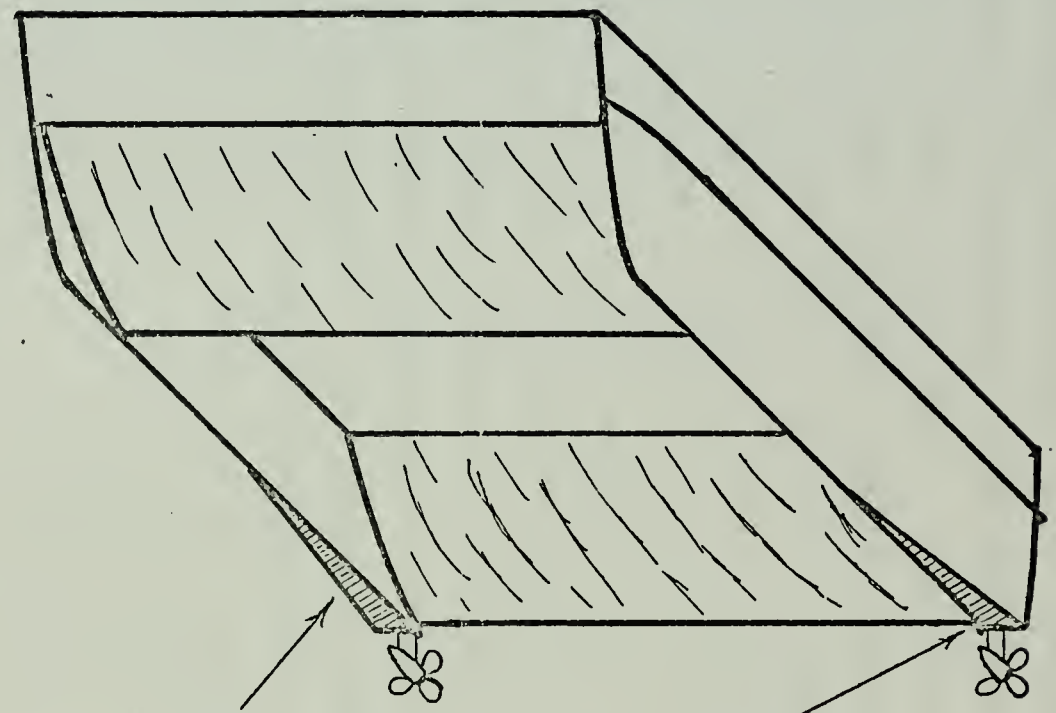


FIGURE 48

BOTTOM VIEW OF THE XR-3 SHOWING PLANING AREAS AT THE REAR

into account the underwater body shape. This shape changes radically from bow to stern. Whether or not this shape has significant effect on roll and pitch transient behavior is not known but should be investigated. Another aspect of the sidewall modeling which should be investigated is the inclusion of forces due to the displacement of water per unit of time. A term such as this would not only have terms based on draft and pitch angle but would also include terms which took into account the rate of change of displacement and the rate of change of the pitch angle. The addition of first derivative terms such as these would have a definite effect on the transient behavior of the sidewalls.

A third area of study concerning the sidewalls is the effect of sidewall deadrise on turning performance. Modeling of the deadrise forces would be incorporated in the cross-flow force modeling. This deadrise could have significant effect on the outboard sidewall during a turn determining whether it has a tendency to rise and ride over the water as the craft skids or dig in and cause the craft to undergo violent roll motion as reported in Ref. 6.

Another area of study which needs investigation is the effect of plenum pressure on the transient response (of the computer model). If it can be shown that the computer model as presently configured can be made to duplicate actual measured craft transient motion by just adjusting the plenum pressure, further modifications of the program may be unnecessary. Further transient motion studies are

needed where both the plenum pressure and the seal pressures are included in the recorded data. Because of the stochastic nature of the actual measured data many duplicate runs will be needed to arrive at accurate averages of the test craft's oscillation frequencies and the decay time constants. These averages should then be used in comparing the actual craft with the computer model.

As can be seen in the recorded data presented herein a fruitful area of study would be in reducing the signal noise on the recorded data. This could be in the recording phase or processing phase of the data. Thorough tests under controlled conditions need to be made of the actual transfer characteristics of the different sensors installed in the test craft.

Earlier in this report it was mentioned that there existed steady state roll and pitch oscillations while the boat was traveling straight on calm water. These oscillations could exist and could be the result of the craft being in some limit cycle type of motion because of the inherent nonlinearity of vehicles operating in fluid mediums. On the other hand, it could be the result of instrumentation for example if the vertical seeking gyro from which all roll and pitch motions are derived was precessing about the true vertical then it could impose a sinusoidal oscillation signal on both the pitch and roll sensors that would show up in the recorded data.

In conclusion it must be stated that there are still many areas in this subject of sidewall modeling of the XR-3 which should and need to be explored before the XR-3 model as originally stated in Ref. 3 and modified herein can be accepted as a reasonably accurate representation of the actual XR-3 test craft. Further investigation into the data collection and processing is also needed to refine the processed data to the point where it is accurate enough for dynamic studies.

APPENDIX A

LISTING OF BOWSEAL SUBROUTINE 'BOWSL'

The entering arguments needed for the new bow seal routine are the same as presented in Ref. 3 for the original bow seal except that instead of entering the angle between the leading edge and craft vertical in columns 46-55, the length of the rear cables is entered (in feet). An additional card is needed to enter the length of the middle support cables. The new data card should be entered as shown below.

CARD	COLUMNS	FORMAT	ENTRY
1	1- 5	I	00601 – control tag
	6-15	F	X coordinate of seal hinge (ft) forward of transom
	16-25	F	Seal leakage orifice coefficient
	26-35	F	Pressure differential between bow seal and plenum chamber (PSF)
	36-45	F	Z coordinate of seal hinge (ft) above keel
	46-55		Length of rear support cable (ft) (1.875 is full down)
	56-65		Length of the seal leading edge (ft)
	66-75		Base leakage area (ft^2) Nominal .08 ft^2)
2	1- 5		00602 – control tag
	6-15		Length of middle support cable (ft) (1.1875 is full down)

```
      SUBROUTINE BOWSL                                                  BSL   10
      INTEGER ON                                                        BSL   20
      COMMON /AIR/ PINF,RHOINF,GAM                                      BSL   30
      COMMON /CONST/ PI,RAD,UO                                          BSL   40
      COMMON /FORBS/ FX,FY,FZ,FK,FM,FN,QL                               BSL   50
      COMMON /GEOM/ WIDTH,XL,XX(4,11),YY(4,11),NSTA(4),AB,VOLNOM,DELS(4,BSL   60
     110),XCP,ZCP                                                       BSL   70
      COMMON /GEOMBS/ DETABX(11),DETABT(11),ARM1B(10),ARM2B(10),DFBS(10)BSL   80
     1,TSKIB(10)                                                        BSL   90
      COMMON /LEAKER/ ALEAK,BLEAK,CFSS,CFBS                             BSL  100
      COMMON /MASSES/ AM,AIXX,AIYY,AIZZ,AIXZ,AIMAX,G,WEIGHT,RHO,NMASS,AMBSL  110
     1I(20),XI(20),YI(20),ZI(20),XS,ZS,HRHO                             BSL  120
      COMMON /PRTINT/ ON,IACCEL,IVEL,ITRAJ,ISTDWL,IBOWSL,ISTNSL,IWAVES,IBSL  130
     1RUD,IPROP,IAEROD,IRHS                                             BSL  140
      COMMON /SLOPE/ WATSLP,XPWV,XLXPWV,PWVHT,XPWVXS                    BSL  150
      COMMON /SOFTBS/ XBF,PBS,SINBS,COSBS,XBS,ZBS,DELYBS,DPBS,ELMAXB,YAVBSL  160
     1GB(10),CENCAB                                                     BSL  170
      COMMON /VARBLE/ VAL(40)                                           BSL  180
      COMMON /WAVE/ ETA(4,11),AW(10),OMEGA(10),DVOLW,NWAVE,BETA,FXWAV,FYBSL  190
     1WAV,FZWAV,FKWAV,FMWAV,FNWAV,ZBAR,PHIBAR,THEBAR,TC,COSBET,SINBET,PBBSL  200
     2BAR                                                               BSL  210
      DIMENSION ELSKID(11), WETLEN(11), BWSL(6,24), GAP(11), ELSKI(11), BSL  220
     1DPFT(11), WTAB(6), ZTAB(6)                                        BSL  230
      DATA NPTS,IBS/6,0/                                                BSL  240
      DATA WTAB/0.0,3.75,5.42,6.67,7.5,8.42/                            BSL  250
      DATA ZTAB/3.75,4.00,4.42,4.83,5.25,5.67/                          BSL  260
      DATA ENU,UWSKI,CLSKI,HINGHT/1.28E-05,0.0,1.5708,1.875/            BSL  270
      DATA BWSL/0.0,3.8,6.9,9.9,12.3,15.0,0.0,4.1,7.3,10.5,13.2,15.7,0.0BSL  280
     1,4.3,7.7,11.0,13.7,16.7,0.0,4.7,8.2,11.5,14.5,17.4,0.0,5.2,8.9,12.BSL  290
     24,15.4,18.3,0.0,5.5,9.6,13.3,16.1,19.6,0.0,5.8,9.9,13.8,17.1,20.6,BSL  300
     30.0,6.1,10.6,14.7,18.4,21.9,0.0,6.4,11.0,15.3,19.3,23.3,0.0,6.6,11BSL  310
     4.7,16.4,20.5,24.5,0.0,6.9,12.3,17.6,22.1,25.7,0.0,7.2,13.5,19.6,24BSL  320
     5.1,28.3,0.0,8.2,15.3,21.7,26.3,31.3,0.0,9.6,17.5,24.2,29.7,34.6,0.BSL  330
     60,11.9,20.0,26.7,32.3,38.0,0.0,14.0,22.5,30.0,35.8,41.0,0.0,17.5,2BSL  340
     75.5,32.5,39.7,44.5,0.0,21.0,30.0,37.4,42.0,47.0,0.0,24.6,33.7,41.0BSL  350
     8,45.0,48.7,0.0,29.4,38.5,45.0,48.7,48.7,0.0,33.0,45.0,48.7,48.7,48BSL  360
     9.7,0.0,40.0,48.7,48.7,48.7,48.7,0.0,48.7,48.7,48.7,48.7,48.7,0.0,4BSL  370
     $8.7,48.7,48.7,48.7,48.7/                                          BSL  380
      DATA CORLEN/3.75/                                                 BSL  390
      EQUIVALENCE (VAL(1),TIME), (VAL(2),U), (VAL(3),V), (VAL(4),W), (VABSL  400
     1L(5),P), (VAL(6),Q), (VAL(7),R), (VAL(8),PHI), (VAL(9),THETA), (VABSL  410
     2L(10),Z), (VAL(11),BMASS), (VAL(21),X), (VAL(22),Y), (VAL(23),PSI)BSL  420
     3, (VAL(24),PB)                                                    BSL  430
C                                                                       BSL  440
      DO 1 J=1,11                                                       BSL  450
      GAP(J) = 0.0                                                      BSL  460
      ELSKI(J) = 0.0                                                    BSL  470
      WETLEN(J) = 0.0                                                   BSL  480
```

```
      ELSKID(J) = 0.0                                                          BSL  490
    1 CONTINUE                                                                 BSL  500
C                                                                              BSL  510
      ALBS = 0.0                                                               BSL  520
      FX = 0.0                                                                 BSL  530
      FZ = 0.0                                                                 BSL  540
      FK = 0.0                                                                 BSL  550
      FM = 0.0                                                                 BSL  560
      FN = 0.0                                                                 BSL  570
      DELPBG = PBS-PB                                                          BSL  580
      IF (DELPBG.LT.0.0) DELPBG=0.0                                            BSL  590
      PBAR = PB-PINF                                                           BSL  600
      DELP = PBAR                                                              BSL  610
      IF (DELP.LT.0.0) DELP=0.0                                                BSL  620
      ARGO = ELMAXB/CORLEN                                                     BSL  630
      ANGO = ARSIN(ARGO)                                                       BSL  640
      X1 = XBS+ZBS*THETA-CORLEN*COS(ANGO)                                      BSL  650
      Z1 = -Z-ZBS+XBS*THETA-ELMAXB*COS(THETA)                                  BSL  660
      DPTHFT = (5.5/(1.+(U/25.))**2.0)/12.0                                    BSL  670
      IF (CENCAB.GT.1.1875) CENCAB=1.1875                                      BSL  680
      N = NSTA(3)                                                              BSL  690
C                                                                              BSL  700
      DO 3 K=1,N                                                               BSL  710
      DPFT(K) = DPTHFT                                                         BSL  720
      ELSKI(K) = (ETA(3,K)-DETABX(K)*(XX(3,K)-X1)-Z1)+YY(3,K)*PHI+XLXPWVBSL  730
     1*WATSLP                                                                  BSL  740
      IF (ELSKI(K).GT.HINGHT) ELSKI(K)=HINGHT                                  BSL  750
      IF ((HINGHT-ELSKI(K)+DPFT(K)).GE.ELMAXB) DPFT(K)=ELMAXB-HINGHT+ELSBSL  760
     1KI(K)                                                                    BSL  770
      IF (DPFT(K).LT.0.0) DPFT(K)=0.0                                          BSL  780
      ELSKID(K) = (ELSKI(K)-DPFT(K))*12.0                                      BSL  790
      IF ((HINGHT-ELSKID(K)/12.0).GE.ELMAXB) ELSKID(K)=(HINGHT-ELMAXB)*1BSL  800
     12.0                                                                      BSL  810
      DPIN = DPFT(K)*12.0                                                      BSL  820
      MM = DPIN                                                                BSL  830
      MM1 = MM+1                                                               BSL  840
      MM2 = MM1+1                                                              BSL  850
      DINC = DPIN-MM                                                           BSL  860
      GAP(K) = -ELSKI(K)+(HINGHT-ELMAXB)                                       BSL  870
      IF (GAP(K).LT.0.0) GAP(K)=0.0                                            BSL  880
      IF (ELSKID(K).GE.0.) GO TO 2                                             BSL  890
      WETLEN(K) = ELSKI(K)                                                     BSL  900
      GO TO 3                                                                  BSL  910
    2 MM3 = ELSKID(K)                                                          BSL  920
      MM4 = MM3+1                                                              BSL  930
      MM5 = MM4+1                                                              BSL  940
      DLINC = ELSKID(K)-MM3                                                    BSL  950
      BWSL1 = BWSL(MM1,MM4)                                                    BSL  960
```

```
      BWSL2 = BWSL(MM1,MM5)                                                  BSL  970
      BWSL3 = BWSL(MM2,MM4)                                                  BSL  980
      BWSL4 = BWSL(MM2,MM5)                                                  BSL  990
      BWSLA1 = (BWSL2-BWSL1)*DLINC+BWSL1                                     BSL 1000
      BWSLA2 = (BWSL4-BWSL3)*DLINC+BWSL3                                     BSL 1010
      WETLEN(K) = ((BWSLA2-BWSLA1)*DINC+BWSLA1)/12.0                         BSL 1020
    3 CONTINUE                                                               BSL 1030
C                                                                            BSL 1040
      N = NSTA(3)-1                                                          BSL 1050
C                                                                            BSL 1060
      DO 10 J=1,N                                                            BSL 1070
      WETLAV = (WETLEN(J+1)+WETLEN(J))/2.0                                   BSL 1080
      IF (WETLAV.LE.0.001) GO TO 8                                           BSL 1090
      DPFTAV = (DPFT(J+1)+DPFT(J))/2.0                                       BSL 1100
      ELSKIA = (ELSKI(J+1)+ELSKI(J))/2.0                                     BSL 1110
      ELSKDA = (ELSKID(J+1)+ELSKID(J))/24.0                                  BSL 1120
      SEALHT = HINGHT-ELSKDA                                                 BSL 1130
      DIFF = 2.0*CENCAB-(SEALHT+0.5)                                         BSL 1140
      IF (DIFF.GT.0.5) DIFF=0.5                                              BSL 1150
      ARM1B(J) = X1+WETLAV/2.0                                               BSL 1160
      ARM2B(J) = ZS-ELSKIA+DPFTAV/2.0                                        BSL 1170
      IF (DIFF.GE.0.25) GO TO 4                                              BSL 1180
      DFBS(J) = -DELP*DELYBS*WETLAV                                          BSL 1190
      GO TO 7                                                                BSL 1200
    4 FORLEN = XBF-WETLAV                                                    BSL 1210
      IF (FORLEN.EQ.0.0) GO TO 5                                             BSL 1220
      ARGW = (HINGHT-ELSKIA)/FORLEN                                          BSL 1230
      IF (ARGW.GT.1.0) ARGW=1.0                                              BSL 1240
      ANGW = ARSIN(ARGW)                                                     BSL 1250
      FORCOS = COS(ANGW)                                                     BSL 1260
      GO TO 6                                                                BSL 1270
    5 FORCOS = 0.0                                                           BSL 1280
    6 DFBS(J) = -DELP*DELYBS*WETLAV-DELP*FORLEN*DELYBS*FORCOS*((FORLEN*0BSL 1290
     1.5*FORCOS)/(FORLEN*FORCOS+WETLAV/2.0))*((DIFF-0.25)*4.0)               BSL 1300
    7 ARG = 0.5*RHO*U*U*WETLAV*DELYBS                                        BSL 1310
      RESKI = U*WETLAV/ENU                                                   BSL 1320
      CDTSKI = 0.427/(ALOG10(RESKI)-0.407)**2.64                             BSL 1330
      TSKIB(J) = -ARG*CDTSKI                                                 BSL 1340
      GO TO 9                                                                BSL 1350
    8 DFBS(J) = 0.0                                                          BSL 1360
      TSKIB(J) = 0.0                                                         BSL 1370
    9 CONTINUE                                                               BSL 1380
      FX = FX+TSKIB(J)                                                       BSL 1390
      FZ = FZ+DFBS(J)                                                        BSL 1400
      FK = FK+DFBS(J)*YAVGB(J)                                               BSL 1410
      FM = FM-DFBS(J)*ARM1B(J)+TSKIB(J)*ARM2B(J)                             BSL 1420
      FN = FN-TSKIB(J)*YAVGB(J)                                              BSL 1430
      ALBS = ALBS+(GAP(J)+GAP(J+1))*DELYBS/2.0                               BSL 1440
```

```
   10 CONTINUE                                                          BSL 1450
C                                                                       BSL 1460
      ALBS = ALBS+BLEAK                                                 BSL 1470
      SQFAC = SQRT(2.*ABS(PBAR)/RHOINF)                                 BSL 1480
      QL = CFBS*ALBS*SQFAC*SIGN(1.,PBAR)                                BSL 1490
      IF (IBOWSL.NE.ON) RETURN                                          BSL 1500
      WRITE (6,11) GAP,WETLEN,FX,FY,FZ,FK,FM,FN                         BSL 1510
      RETURN                                                            BSL 1520
C                                                                       BSL 1530
   11 FORMAT (//10X,8HBOW SEAL/26H GAP (FT.) (PORT TO STBD.)/11F10.5/28HBSL 1540
     1 WETLEN(FT.) (PORT TO STBD.)/11F10.5/10X,23HBOWSL FX,FY,FZ,FK,FM,FBSL 1550
     2N/6E15.4)                                                         BSL 1560
      END                                                               BSL 1570
```

APPENDIX B

LISTING OF STERN SEAL SUBROUTINE 'STNSL'

The entries for this routine are the same as the original stern seal except that in columns 46-55 the rear support cable length is entered instead of the seal angle.

Block 5 entries are as follows:

CARD	COLUMNS	FORMAT	ENTRY
1	1- 5	I	00500 — control tag
	6-15	F	X coordinate of seal hinge, (ft) forward of transom
	16-25	F	Z coordinate of seal hinge above keel (ft)
	26-35	F	Base leakage area (ft^2) 3.79 nominal
	36-45	F	Seal leakage orifice coefficient
	46-55	F	Length of rear support cable (ft) 1.875 is full down
	56-65	F	Pressure differential between stern seal and plenum chamber (PSF)
	66-75	F	Length of the leading edge of the seal (ft)

```
      AGAP = ELSKLA-ELSKIA                                                    SSL  970
      AGAP1 = AGAP                                                            SSL  980
      IF (AGAP.LT.GPS) AGAP=GPS                                               SSL  990
      IF (AGAP1.GT.GPS) AGAP1=GPS                                             SSL 1000
      ARM1S(J) = XX(4,J)+ELSKIA/2.                                            SSL 1010
      ARM2S(J) = ZS-ELSKIA                                                    SSL 1020
      DFSS(J) = -DELP*DELYSS*AIRLAV/(GPS/AGAP)**2.0                           SSL 1030
      IF (AIRLAV.LE.0.0) GO TO 3                                              SSL 1040
      ARG = .5*RHO*U*U*AIRLAV*DELYSS                                          SSL 1050
      RESKI = U*AIRLAV/ENU                                                    SSL 1060
      CDTSKI = .427/(ALOG10(RESKI)-.407)**2.64                                SSL 1070
      TSKIS(J) = -ARG*CDTSKI                                                  SSL 1080
C     THE FOLLOWING CARD REMOVES WATER DRAG EFFECTS OF STERN SEAL             SSL 1090
      TSKIS(J) = 0.0                                                          SSL 1100
      GO TO 4                                                                 SSL 1110
    3 TSKIS(J) = 0.0                                                          SSL 1120
    4 CONTINUE                                                                SSL 1130
      FX = FX+TSKIS(J)                                                        SSL 1140
      FZ = FZ+DFSS(J)                                                         SSL 1150
      FK = FK+DFSS(J)*YAVGS(J)                                                SSL 1160
      FM = FM-DFSS(J)*ARM1S(J)+TSKIS(J)*ARM2S(J)                              SSL 1170
      FN = FN-TSKIS(J)*YAVGS(J)                                               SSL 1180
      ALSS = ALSS+(GAP(J)+GAP(J+1))*DELYSS/2.0                                SSL 1190
      AGAP2 = AGAP2+AGAP1                                                     SSL 1200
      AGAPA1 = AGAP2/J                                                        SSL 1210
    5 CONTINUE                                                                SSL 1220
C                                                                             SSL 1230
      ALSS = ALSS+ALEAK*(AGAPA1/GPS)                                          SSL 1240
      SQFAC = SQRT(2.*ABS(PBAR)/RHOINF)                                       SSL 1250
      QL = CFSS*ALSS*SQFAC*SIGN(1.,PBAR)                                      SSL 1260
      IF (ISTNSL.NE.ON) RETURN                                                SSL 1270
      WRITE (6,6) GAP,AIRLEN,FX,FY,FZ,FK,FM,FN                                SSL 1280
      RETURN                                                                  SSL 1290
C                                                                             SSL 1300
    6 FORMAT (//12H  STERN SEAL/26H  GAP (FT.) PORT TO STBD. /11E11.3/28SSL 1310
     1H  AIRLEN(FT.) PORT TO STBD. /11E11.3/10X,23HSTNSL FX,FY,FZ,FK,FM,SSL 1320
     2FN/6E15.4)                                                              SSL 1330
      END                                                                     SSL 1340
```

```
      SUBROUTINE STNSL                                                  SSL   10
      INTEGER ON                                                        SSL   20
      COMMON /AIR/ PINF,RHOINF,GAM                                      SSL   30
      COMMON /CONST/ PI,RAD,UO                                          SSL   40
      COMMON /FORSS/ FX,FY,FZ,FK,FM,FN,QL,FMS                           SSL   50
      COMMON /GEOM/ WIDTH,XL,XX(4,11),YY(4,11),NSTA(4),AB,VOLNOM,DELS(4,SSL   60
     110),XCP,ZCP                                                       SSL   70
      COMMON /GEOMSS/ DETADX(11),DETADT(11),ARM1S(10),DFSS(10),TSKIS(10)SSL   80
     1,ARM2S(10)                                                        SSL   90
      COMMON /KSWTCH/ ITHRST                                            SSL  100
      COMMON /LEAKER/ ALEAK,CFSS                                        SSL  110
      COMMON /MASSES/ AM,AIXX,AIYY,AIZZ,AIXZ,AIMAX,G,WEIGHT,RHO,NMASS,AMSSL  120
     1I(20),XI(20),YI(20),ZI(20),XS,ZS,HRHO                             SSL  130
      COMMON /PRTINT/ ON,IACCEL,IVEL,ITRAJ,ISIDWL,IBOWSL,ISTNSL,IWAVES,ISSL  140
     1RUD,IPROP,IAEROD,IRHS                                             SSL  150
      COMMON /SOFTSS/ XLF,PSS,SINTH,COSTH,XSS,ZSS,DELYSS,DPSS,ELMAXS,YAVSSL  160
     1GS(10)                                                            SSL  170
      COMMON /STSLR/ CPHI,CPHID                                         SSL  180
      COMMON /VALOLD/ YOLD(20)                                          SSL  190
      COMMON /VARBLE/ VAL(40)                                           SSL  200
      COMMON /WAVE/ ETA(4,11),AW(10),OMEGA(10),DVOLW,NWAVE,BETA,FXWAV,FYSSL  210
     1WAV,FZWAV,FKWAV,FMWAV,FNWAV,ZBAR,PHIBAR,THEBAR,TC,COSBET,SINBET,PBSSL  220
     2BAR                                                               SSL  230
      EQUIVALENCE (VAL(1),TIME), (VAL(2),U), (VAL(3),V), (VAL(4),W), (VASSL  240
     1L(5),P), (VAL(6),Q), (VAL(7),R), (VAL(8),PHI), (VAL(9),THETA), (VASSL  250
     2L(10),Z), (VAL(11),BMASS), (VAL(21),X), (VAL(22),Y), (VAL(23),PSI)SSL  260
     3, (VAL(24),PB)                                                    SSL  270
      DIMENSION GAP(11), ELSKI(11), ELSKIL(11), AIRLEN(11), CTNSL(6,24) SSL  280
      DATA ENU,UWSKI,CLSKI,GPS,HINGHT/1.28E-5,0.0,1.5708,.4644,1.875/   SSL  290
      DATA CTNSL/0.0,3.8,7.0,9.9,12.3,15.0,0.0,4.1,7.3,10.5,13.2,15.7,0.SSL  300
     10,4.3,7.7,11.0,13.7,16.7,0.0,4.7,8.2,11.5,14.5,17.4,0.0,5.2,8.9,12SSL  310
     2.4,15.4,18.3,0.0,5.5,9.4,13.1,16.1,19.2,0.0,5.8,9.9,13.8,17.1,20.6SSL  320
     3,0.0,6.1,10.6,14.7,18.4,21.9,0.0,6.4,11.0,15.3,19.3,23.3,0.0,6.6,1SSL  330
     41.7,16.4,20.5,24.5,0.0,6.9,12.3,17.6,22.1,25.7,0.0,7.2,13.5,19.6,2SSL  340
     54.1,28.3,0.0,8.2,15.3,22.1,26.3,30.8,0.0,9.6,17.5,24.2,29.7,34.6,0SSL  350
     6.0,11.9,20.0,25.4,32.3,38.0,0.0,14.0,23.3,30.0,35.8,41.0,0.0,17.5,SSL  360
     725.5,32.5,39.7,44.5,0.0,21.6,30.0,38.7,42.0,47.0,0.0,24.6,33.7,41.SSL  370
     80,45.0,48.7,0.0,28.3,38.5,45.0,48.7,48.7,0.0,35.0,45.0,48.7,48.7,4SSL  380
     98.7,0.0,40.0,48.7,48.7,48.7,48.7,0.0,48.7,48.7,48.7,48.7,48.7,0.0,SSL  390
     $48.7,48.7,48.7,48.7,48.7/                                         SSL  400
      IF (ELMAXS.GT.HINGHT) ELMAXS=HINGHT                               SSL  410
C                                                                       SSL  420
      DO 1 J=1,11                                                       SSL  430
      GAP(J) = 0.0                                                      SSL  440
      ELSKI(J) = 0.0                                                    SSL  450
      ELSKIL(J) = 0.0                                                   SSL  460
      AIRLEN(J) = 0.0                                                   SSL  470
    1 CONTINUE                                                          SSL  480
```

```
C                                                                       SSL  490
C     'EFDEP' IS THE EFFECTIVE LIFTING DEPTH OF THE STERN SEAL          SSL  500
      EFDEP = 6.0                                                       SSL  510
      MM = EFDEP                                                        SSL  520
      ALSS = 0.0                                                        SSL  530
      FX = 0.0                                                          SSL  540
      FZ = 0.0                                                          SSL  550
      FK = 0.0                                                          SSL  560
      FM = 0.0                                                          SSL  570
      FN = 0.0                                                          SSL  580
      AGAP1 = 0.0                                                       SSL  590
      AGAP2 = 0.0                                                       SSL  600
      AGAPA1 = 0.0                                                      SSL  610
      DELP = PSS-PB                                                     SSL  620
      IF (DELP.LT.0.0) DELP=0.0                                         SSL  630
      PBAR = PB-PINF                                                    SSL  640
C     CALCULATE ELSKI HERE.                                             SSL  650
      SINDIF = SINTH-COSTH*THETA                                        SSL  660
      COSDIF = COSTH+SINTH*THETA                                        SSL  670
      X1 = XSS+ZSS*THETA-XLF*SINDIF                                     SSL  680
      Z1 = (-Z-ZSS+XSS*THETA-ELMAXS*COS(THETA))                         SSL  690
C     CALCULATE GAP HERE.                                               SSL  700
      N = NSTA(4)                                                       SSL  710
C                                                                       SSL  720
      DO 2 K=1,N                                                        SSL  730
      ELSKI(K) = (ETA(4,K)-DETADX(K)*(XX(4,K)-X1)-Z1)+YY(4,K)*PHI       SSL  740
      IF (ELSKI(K).GT.HINGHT) ELSKI(K)=HINGHT                           SSL  750
      ELSKIL(K) = ELSKI(K)+GPS                                          SSL  760
      IF (ELSKIL(K).GT.HINGHT) ELSKIL(K)=HINGHT                         SSL  770
      IF (ELSKIL(K).LT.(HINGHT-ELMAXS)) ELSKIL(K)=HINGHT-ELMAXS         SSL  780
      GAP(K) = -ELSKI(K)+(HINGHT-ELMAXS)                                SSL  790
      IF (GAP(K).LT.0.0) GAP(K)=0.0                                     SSL  800
      MM1 = ELSKIL(K)*12.0                                              SSL  810
      MM2 = MM1+1                                                       SSL  820
      MM3 = MM2+1                                                       SSL  830
      DLINC = ELSKIL(K)*12.0-MM1                                        SSL  840
      STNSL1 = CTNSL(MM,MM2)                                            SSL  850
      STNSL2 = CTNSL(MM,MM3)                                            SSL  860
      AIRLEN(K) = ((STNSL2-STNSL1)*DLINC+STNSL1)/12.0                   SSL  870
    2 CONTINUE                                                          SSL  880
C                                                                       SSL  890
      N = NSTA(4)-1                                                     SSL  900
C                                                                       SSL  910
C                                                                       SSL  920
      DO 5 J=1,N                                                        SSL  930
      ELSKIA = (ELSKI(J+1)+ELSKI(J))/2.                                 SSL  940
      ELSKLA = (ELSKIL(J+1)+ELSKIL(J))/2.0                              SSL  950
      AIRLAV = (AIRLEN(J+1)+AIRLEN(J))/2.0                              SSL  960
```

APPENDIX C

LISTING OF FAN SUBROUTINE 'FAN'

The entries for the fan subroutine remain the same. The nominal fan RPM is 8000 RPM vice 2615 RPM. Printed below are copies of the appropriate entries for the bow seal, stern seal and main plenum fans.

```
01901  2.0          8000.0  19.0          1.0
-10.406   -5.203      0.0       5.203     10.406    15.609    18.211    20.812
 23.414   26.015     28.617     31.218     33.820    36.421    41.624    46.827
 52.030   57.233     62.436
 22.7     22.067     20.67     19.60      18.367    17.133    16.467    15.10
 12.20    10.00      7.80       6.40       5.20      4.33      2.60      .983
 -.020    -1.06      -2.03
01902  2.0          8000.0  19.0          1.0
-10.406   -5.203      0.0       5.203     10.406    15.609    18.211    20.812
 23.414   26.015     28.617     31.218     33.820    36.421    41.624    46.827
 52.030   57.233     62.436
 22.7     22.067     20.67     19.60      18.367    17.133    16.467    15.10
 12.20    10.00      7.80       6.40       5.20      4.33      2.60      .983
 -.020    -1.06      -2.03
01903  1.0          8000.0  19.0          1.0
-10.406   -5.203      0.0       5.203     10.406    15.609    18.211    20.812
 23.414   26.015     28.617     31.218     33.820    36.421    41.624    46.827
 52.030   57.233     62.436
 25.70    24.33      23.167    21.83      20.61     19.33     18.85     17.73
 16.40    12.60      10.367     8.033      6.331     5.073     3.035     1.60
 0.00     -1.06      -2.03
```

```
      SUBROUTINE FAN                                                    FAN   10
      INTEGER ON                                                        FAN   20
      COMMON /AIR/ PINF,RHOINF,GAM                                      FAN   30
      COMMON /FANMAP/ QIN,QBFAN(25),QMFAN(25),QSFAN(25),ENBFAN,ENMFAN,ENFAN   40
     1SFAN,BRPM,EMRPM,SRPM,NPTSB,NPTSM,NPTSS,PBFAN(25),PMFAN(25),PSFAN(2FAN   50
     25),TMEB(25),DELB(25),NB,TMES(25),DELS(25),NS                      FAN   60
      COMMON /PRTINT/ ON,IACCEL,IVEL,ITRAJ,ISIDWL,IBOWSL,ISTNSL,IWAVES,IFAN   70
     1RUD,IPROP,IAEROD,IRHS                                             FAN   80
      COMMON /SOFTBS/ XBF,PBS,SINBS,COSBS,XBS,ZBS,DELYBS,DPBS,ELMAXB,YAVFAN   90
     1GB(10)                                                            FAN  100
      COMMON /SOFTSS/ XLF,PSS,SINTH,COSTH,XSS,ZSS,DELYSS,DPSS,ELMAXS,YAVFAN  110
     1GS(10)                                                            FAN  120
      COMMON /VARBLE/ VAL(40)                                           FAN  130
      DIMENSION QB(1), QM(1), QS(1), PBOW(1), PM(1), PS(1), HP(8)       FAN  140
      EQUIVALENCE (VAL(1),TIME), (VAL(2),U), (VAL(3),V), (VAL(4),W), (VAFAN  150
     1L(5),P), (VAL(6),Q), (VAL(7),R), (VAL(8),PHI), (VAL(9),THETA), (VAFAN  160
     2L(10),Z), (VAL(11),BMASS), (VAL(21),X), (VAL(22),Y), (VAL(23),PSI)FAN  170
     3, (VAL(24),PB)                                                    FAN  180
      EQUIVALENCE (VAL(18),FANPWR)                                      FAN  190
      EQUIVALENCE (QBFAN(1),QB(1)), (QMFAN(1),QM(1)), (QSFAN(1),QS(1)), FAN  200
     1(PBFAN(1),PBOW(1)), (PMFAN(1),PM(1)), (PSFAN(1),PS(1))            FAN  210
      DATA HP/2.9,2.3,1.95,1.77,1.85,2.05,1.93,1.62/                    FAN  220
      BRAT = 8000/BRPM                                                  FAN  230
      EMRAT = 8000/EMRPM                                                FAN  240
      SRAT = 8000/SRPM                                                  FAN  250
      TL = VAL(1)                                                       FAN  260
      IF (NB.EQ.0.0) GO TO 1                                            FAN  270
      DPBS = FG1(TL,NB,TMEB,DELB,ILB)                                   FAN  280
      PBS = PB+DPBS                                                     FAN  290
    1 IF (NS.EQ.0.0) GO TO 2                                            FAN  300
      DPSS = FG1(TL,NS,TMES,DELS,ILS)                                   FAN  310
      PSS = PB+DPSS                                                     FAN  320
    2 CONTINUE                                                          FAN  330
      PB1 = PBS-PINF                                                    FAN  340
      PB2 = PB-PINF                                                     FAN  350
      PB3 = PSS-PINF                                                    FAN  360
      PBARB = PB1*BRAT**2                                               FAN  370
      PBARM = PB2*EMRAT**2                                              FAN  380
      PBARS = PB3*SRAT**2                                               FAN  390
      QBOW = ENBFAN*FG1(PBARB,NPTSB,PBOW,QB,IB)/BRAT                    FAN  400
      QMAIN = ENMFAN*FG1(PBARM,NPTSM,PM,QM,IM)/EMRAT                    FAN  410
      QSTN = ENSFAN*FG1(PBARS,NPTSS,PS,QS,IS)/SRAT                      FAN  420
      QIN = QBOW+QMAIN+QSTN                                             FAN  430
      MB1 = (QBOW/ENBFAN+5.0)/5.0                                       FAN  440
      MB2 = MB1+1                                                       FAN  450
      MB3 = MB2+1                                                       FAN  460
      BINC = ((QBOW/ENBFAN+5.0)-MB1*5.0)/5.0                            FAN  470
      BFANHP = ((HP(MB3)-HP(MB2))*BINC+HP(MB2))*ENBFAN*(1./BRAT)**3.0   FAN  480
```

```
      MS1 = (QSTN/ENSFAN+5.0)/5.0                                                    FAN  490
      MS2 = MS1+1                                                                    FAN  500
      MS3 = MS2+1                                                                    FAN  510
      STINC = ((QSTN/ENSFAN+5.0)-MS1*5.0)/5.0                                        FAN  520
      SFANHP = ((HP(MS3)-HP(MS2))*STINC+HP(MS2))*ENSFAN*(1./SRAT)**3.0               FAN  530
      MM1 = (QMAIN/ENMFAN+5.0)/5.0                                                   FAN  540
      MM2 = MM1+1                                                                    FAN  550
      MM3 = MM2+1                                                                    FAN  560
      PLINC = ((QMAIN/ENMFAN+5.0)-MM1*5.0)/5.0                                       FAN  570
      PFANHP = ((HP(MM3)-HP(MM2))*PLINC+HP(MM2))*ENMFAN*(1./EMRAT)**3.0              FAN  580
      RELPWR = PFANHP+BFANHP+SFANHP                                                  FAN  590
      FANPWR = (QBOW*PB1+QMAIN*PB2+QSTN*PB3)/550.                                    FAN  600
      FANEFF = FANPWR/RELPWR                                                         FAN  610
      IF (IRHS.NE.ON) RETURN                                                         FAN  620
      WRITE (6,3) QBOW,QMAIN,QSTN,PBARB,PBARM,PBARS,RELPWR,FANPWR,FANEFF             FAN  630
      RETURN                                                                         FAN  640
C                                                                                    FAN  650
    3 FORMAT (//4H FAN/32H Q - BOW,MAIN,STERN (CU FT /SEC)3F12.1/28H DELFAN  660
     1P - BOW,MAIN,STERN (PSF)3F11.2/60H ACTUAL FAN POWER REQUIRED(HP), FAN  670
     2IDEAL FAN POWER, EFFICIENCY 3F12.4)                                            FAN  680
      END                                                                            FAN  690
```

APPENDIX D

LISTING OF INITIAL CONDITION SUBROUTINE INCON

The INCON subroutine was modified to permit it to calculate the wave components of the various sea states if desired instead of having to enter each component individually.

Block 11 options 1 and 2 remain identical. New options 3 and 4 have been added and are entered as follows:

BLOCK 11 - OPTION TAG 3

CARD	COLUMNS	FORMAT	ENTRY
1	1- 5	I	01103 control and option tag
	6-15	F	Number of wave components maximum of 10
	16-25	F	Initial wave heading (deg) (180 deg = ahead waves)
	26-35	F	Average height of 1/3 highest waves (ft)
	36-45	F	Shortest significant period (sec)
	46-55	F	Longest significant period (sec)

BLOCK 11 - OPTION TAG 4

CARD	COLUMNS	FORMAT	ENTRY
1	1- 5	I	01104 control and option tag
	6-15	F	Number of wave components maximum of 10
	16-25	F	Initial wave heading (deg) (180 deg = ahead waves)
	26-35	F	Average height of 1/3 highest waves (ft)

CARD	COLUMNS	FORMAT	ENTRY
1	36-45	F	Lowest significant frequency (Hz)
	46-55	F	Highest significant frequency (Hz)

```
      SUBROUTINE INCON (TIME)                                                  INC 0010
      REAL*8 TICRD                                                             INC 0020
      INTEGER ON                                                               INC 0030
      COMMON /AIR/ PINF,RHOINF,GAM                                             INC 0040
      COMMON/AXIS/NXYS(26)                                                     INC 0050
      COMMON /BMCO / IMM,IMNX,IMNY,IBMFIL,BTIME,IMT,XMI(10),YMI(7),IX,IYINC 0060
      COMMON /COLUMN/ IVERT,ILATRL                                             INC 0070
      COMMON /CONST/ PI,RAD,UO                                                 INC 0080
      COMMON /CNTRL/CONTW,CONTQ,CONTTH,QMULT,LOUVER,ACONTZ,ACONTW,ZEQUILINC 0090
     1  ,THEQL,ACBASE                                                          INC 0100
      COMMON /CURVE/NCURV(10)                                                  INC 0110
      COMMON/ENGINE/NPS,NPP,THSTS(25),THSTP(25),XP,YP,ZP,STHS,STHP,            INC 0120
     ATIP(25),TIS(25)                                                         INC 0130
      COMMON /EQNCO/ NEQS,TOL(20),JQQ                                          INC 0140
      COMMON /FAIR/ RHOA,XLAERO                                                INC 0150
      COMMON /FANMAP/QIN,QBFAN(25),QMFAN(25),QSFAN(25),ENBFAN,ENMFAN,          INC 0160
     1  ENSFAN,BRPM,EMRPM,SRPM,NPTSB,NPTSM,NPTSS                               INC 0170
     2  ,PBFAN(25),PMFAN(25),PSFAN(25),TMEB(25),DELB(25),NB,TMES(25),          INC 0180
     3DETS(25),NS                                                             INC 0190
      COMMON / FROUDE / FN,FNCRIT                                              INC 0200
      COMMON/GBOW/ XBOW                                                        INC 0210
      COMMON /GEOM/     WIDTH,XL,XX(4,11),YY(4,11),NSTA(4),AB,VOLNOM           INC 0220
     1,DELS(4,10),XCP,ZCP                                                     INC 0230
      COMMON /GEOMSW/ XAVG(10),DS                                              INC 0240
      COMMON/GRAF/NGRAF,NDRW                                                   INC 0250
      COMMON /HEADG/TICRD(6)                                                   INC 0260
      COMMON /PWAVE/ FNCON,PWVCON                                              INC 0270
      COMMON/LEAKER/ALEAK,BLEAK,CFSS,CFBS                                      INC 0280
      COMMON /MASSES/ AM,AIXX,AIYY,AIZZ,AIXZ,AIMAX,G,WEIGHT,RHO,NMASS,         INC 0290
     -                AMI(201),XI(201),YI(201),ZI(201),XS,ZS,HRHO             INC 0300
      COMMON /MATRIX/ A(6,6)                                                   INC 0310
      COMMON /OPTION/ I3DOF,ISRGE,ITRIM,IDIA                                   INC 0320
      COMMON /PLENUM/XLBW,X8BW,ABW,BUBHGT                                      INC 0330
      COMMON/PLVCQQ/NVI,NVD,NLI,NLD                                            INC 0340
      COMMON /PRIME/ STIME,FTIME,DELT,DELPNT,TPRINT                            INC 0350
      COMMON /PRTINT/ON,IACCEL,IVEL,ITRAJ,ISIDWL,IBOWSL,ISTNSL,IWAVES,         INC 0360
     -IRUD,IPROP,IAEROD,IRHS                                                  INC 0370
      COMMON /ROLL/ PHIMAX,TROLL                                               INC 0380
      COMMON/RUDDR/ NPR,DELRUD(25),XR,YR,ZR,IRDS,TL,RSPAN,RAREA,RASPR,         INC 0390
     ARCLB,RTC,RUDANG,TIR(25)                                                 INC 0400
      COMMON /RISER/ AMPTC                                                     INC 0410
      COMMON/SOFTBS/XBF,PBS,SINBS,COSBS,XBS,ZBS,DELYBS,DPBS,ELMAXB,YAVG        INC 0420
     1B(10),CENCAB                                                            INC 0430
      COMMON /SOFTSS/ XLF,PSS,SINTH,COSTH,XSS,ZSS,DELYSS,DPSS                  INC 0440
     1  ,ELMAXS,YAVGS(10)                                                      INC 0450
      COMMON /SIDE/FXSW,FYSW,FZSW,FKSW,FMSW,FNSW,ALSW,YSW,XLSW,CFSW,CDSWINC 0460
     1,VAREA  ,VCHORD,VSPAN,VANGLE,VCOS,VX,VY,VZ  ,AVBMSW,DELX,VTC            INC 0470
      COMMON/SLOPE/WATSLP,XPWV,XLXPWV,PWVHT,XPWVXS                             INC 0480
```

```
      COMMON /STABLE/ S(4),ISTAB                                          INC 0490
      COMMON /STSLR/ CPHI,CPHID                                           INC 0500
      COMMON /SUM/ ISUM1(8),ISUM2(8)                                      INC 0510
      COMMON / VALOLD / YOLD(20)                                          INC 0520
      COMMON /VARBLE/ VAL(40)                                             INC 0530
      COMMON /WAVE/ ETA(4,11),AW(10),OMEGA(10),DVOLW,NWAVE,BETA,          INC 0540
     1               FXWAV,FYWAV,FZWAV,FKWAV,FMWAV,FNWAV                  INC 0550
     2               ,ZBAR,PHIBAR,THEBAR,TC,COSBET,SINBET,PBBAR           INC 0560
      COMMON /WAVEF/WAVLEN(10),OMEGAE(10),WAVSLP(10),ENCPER(10)           INC 0570
      COMMON /WAVTAB/ NAL,DAL,SAL,NDS,DDS,SDS,NTH,DTH,STH,NBB,DBB,SBB,    INC 0580
     1          AC1(20,5,7),AC2(20,5,7),AC3(20,5,7),AC4(20,5,7),         INC 0590
     2          AC5(20,5,7),AC6(20,5,7),AC7(20,5,7)                      INC 0600
     3          ,AC0(20,5,7),AC00(20,5,7),AC8(20,5,7),                   INC 0610
     4          AS1(20,5,7),AS2(20,5,7),AS3(20,5,7),AS4(20,5,7),         INC 0620
     5          AS5(20,5,7),AS6(20,5,7),AS7(20,5,7)                      INC 0630
     6          ,AS0(20,5,7),AS00(20,5,7),AS8(20,5,7)                    INC 0640
     7          ,BB(36),XREF,RX                                          INC 0650
                                                                          INC 0660
      DIMENSION ZZZ(14050)                                                INC 0670
      EQUIVALENCE (ZZZ,NAL)                                               INC 0680
      EQUIVALENCE                (VAL(2),U),(VAL(3),V),(VAL(4),W),        INC 0690
     1(VAL(5),P),(VAL(6),Q),(VAL(7),R),(VAL(8),PHI),(VAL(9),THETA),       INC 0700
     2(VAL(10),Z),(VAL(11),BMASS),(VAL(21),X),(VAL(22),Y),(VAL(23),PSI),INC 0710
     3(VAL(24),PB)                                                        INC 0720
      DIMENSION TEMP(7),XMO(10)                                           INC 0730
      DIMENSION TITLC(20)                                                 INC 0740
      DATA BEAM,BETAD,DELO,DELPI,DLRDO,DSO,ISYS,RMAXO,RONO,RRATO,RREVO,   INC 0750
     1 THETO,THSSI,TPRINO,UO,VXO,VZO,XBSI,XCPO,XLTOT,XPO,XRO,XSSI,YPO,    INC 0760
     2 ZPO,ZRO,ZSSI/ 6*0.0,0,20*0.0/                                      INC 0770
C     INITIAL CONDITIONS WITH WATSLP                                      INC 0780
      DO 9 I=1,8                                                          INC 0790
      ISUM1(I)=0                                                          INC 0800
    9 ISUM2(I)=0                                                          INC 0810
      PINF=2116.                                                          INC 0820
      RHOINF=.002378                                                      INC 0830
      GAM=1.4                                                             INC 0840
      GO TO 10                                                            INC 0850
 2200 READ(5,3000) NGRAF,NDRW                                             INC 0860
 3000 FORMAT(2I2)                                                         INC 0870
      READ(5,3001) NXYS                                                   INC 0880
 3001 FORMAT(26I2)                                                        INC 0890
      READ(5,3002) TICRD                                                  INC 0900
 3002 FORMAT(6A8)                                                         INC 0910
10    READ(5,99) ISYSL,IOPT,(TEMP(I),I=1,7)                               INC 0920
      IF( ISYSL .EQ. ISYS .AND. ISYSL.EQ. 13) GOTO 70                     INC 0930
      ISYS=ISYSL                                                          INC 0940
      IF((ISYS.LE.0).OR.(ISYS.GT.22)) GO TO 70                            INC 0950
      GOTO(100,200,300,400,500,600,700,800,900,1000,1100,1200,1300,       INC 0960
```

```
     11400,1500,1600,1700,1800,1900,2000,2100,2200),ISYS                INC 0970
                                                                        INC 0980
C      PROGRAM CONTROL PARAMETERS                                       INC 0990
100    CONTINUE                                                         INC 1000
       GOTO (101,102,103,104,105),IOPT                                  INC 1010
 101   CONTINUE                                                         INC 1020
       STIME=TEMP(1)                                                    INC 1030
       FTIME=TEMP(2)                                                    INC 1040
       DELO=TEMP(3)                                                     INC 1050
       DELPNT=TEMP(4)                                                   INC 1060
       TPRINO=TEMP(5)                                                   INC 1070
       IF (TPRINO.LT.STIME+DELPNT)  TPRINO = STIME+DELPNT               INC 1080
       IF (DELO.GT.DELPNT) DELO=DELPNT                                  INC 1090
       IF (DELO.EQ.0.0) GO TO 140                                       INC 1100
       GOTO 10                                                          INC 1110
 2000  READ(5,3003) NCURV                                               INC 1120
 3003  FORMAT(10I1)                                                     INC 1130
       GO TO 10                                                         INC 1140
 2100  READ(5,2210) ISUM1                                               INC 1150
       READ(5,2210)ISUM2                                                INC 1160
 2210  FORMAT(8I2)                                                      INC 1170
       GO TO 10                                                         INC 1180
102    READ (5,191) IACCEL,IVEL,ITRAJ,ISIDWL,IBOWSL,ISTNSL,IWAVES,IRUD, INC 1190
     1 IPROP,IAEROD,IRHS                                                INC 1200
       GOTO 10                                                          INC 1210
103    READ (5,175) NEQS,JQQ,(TOL(J),J=1,NEQS)                          INC 1220
       GOTO 10                                                          INC 1230
 104   READ(5,191) IVERT,ILATRL,NVD,NVI,NLD,NLI                         INC 1240
       GO TO 10                                                         INC 1250
 105   CONTINUE                                                         INC 1260
       I3DOF=TEMP(1)                                                    INC 1270
       ISRGE=TEMP(2)                                                    INC 1280
       ITRIM=TEMP(3)                                                    INC 1290
       IDIA=TEMP(4)                                                     INC 1300
       GO TO 10                                                         INC 1310
  140  WRITE(6,195)                                                     INC 1320
       STOP                                                             INC 1330
                                                                        INC 1340
C      MASS DISTRIBUTION                                                INC 1350
  200  G=32.17                                                          INC 1360
       RHO=1.99                                                         INC 1370
       HRHO=RHO/2.                                                      INC 1380
       GO TO (210,220,230), IOPT                                        INC 1390
  210  IMM = 0                                                          INC 1400
       WEIGHT = TEMP(1)                                                 INC 1410
       AM = WEIGHT/G                                                    INC 1420
       XS = TEMP(2)                                                     INC 1430
       ZS = TEMP(3)                                                     INC 1440
```

```
      AIXX = TEMP(4)                                                    INC 1450
      AIYY = TEMP(5)                                                    INC 1460
      AIZZ = TEMP(6)                                                    INC 1470
      AIXZ = TEMP(7)                                                    INC 1480
C     INERTIA MATRIX OPERATIONS                                         INC 1490
  212 DO 211 I=1,6                                                      INC 1500
      DO 211 N=1,6                                                      INC 1510
  211 A(I,N) = 0.0                                                      INC 1520
      DO 213 N=1,3                                                      INC 1530
  213 A(N,N)=AM                                                         INC 1540
      A(4,4)=AIXX                                                       INC 1550
      A(5,5)=AIYY                                                       INC 1560
      A(6,6)=AIZZ                                                       INC 1570
      A(4,6)=-AIXZ                                                      INC 1580
      A(6,4)=-AIXZ                                                      INC 1590
      AIMAX=AMAX1(AM,AIXX,AIYY,AIZZ,ABS(AIXZ))                          INC 1600
      DO 214 I=1,6                                                      INC 1610
      DO 214 J=1,6                                                      INC 1620
  214 A(I,J)=A(I,J)/AIMAX                                               INC 1630
      CALL DMINV (A,6,D)                                                INC 1640
      DO 215 I=1,6                                                      INC 1650
      DO 215 J=1,6                                                      INC 1660
  215 A(I,J)=A(I,J)/AIMAX                                               INC 1670
      IF (D.NE.0.0) GO TO 10                                            INC 1680
      WRITE (6,216)                                                     INC 1690
      STOP                                                              INC 1700
C     READ WEIGHT DISTRIBUTION - ASSUME TRANSVERSE (PORT/STBD) SYMMETRY INC 1710
C        X INPUT DIST. FWD. OF (SIDEWALL) TRANSOM                       INC 1720
C        Y INPUT DIST. TO STARBOARD                                     INC 1730
  220 I = 1                                                             INC 1740
C        Z INPUT DIST. UP FROM KEEL-LINE                                INC 1750
  222 READ (5,192) AMI(I),XI(I),YI(I),ZI(I)                             INC 1760
      IF (AMI(I).LT.0.0)  GO TO 224                                     INC 1770
      I = I+1                                                           INC 1780
      IF ( I.GT.201 )  GO TO 70                                         INC 1790
      GO TO 222                                                         INC 1800
  224 NMASS = I-1                                                       INC 1810
      SUM = 0.0                                                         INC 1820
      SUX = 0.0                                                         INC 1830
      SUZ = 0.0                                                         INC 1840
      DO 225 I=1,NMASS                                                  INC 1850
      AMI(I) = AMI(I)/G                                                 INC 1860
      SUM = SUM+AMI(I)                                                  INC 1870
      SUX = SUX+AMI(I)*XI(I)                                            INC 1880
  225 SUZ = SUZ+AMI(I)*ZI(I)                                            INC 1890
      AM = SUM*2.0                                                      INC 1900
      WEIGHT = AM*G                                                     INC 1910
      ZS  = SUZ/SUM                                                     INC 1920
```

```
      XS  = SUX/SUM                                                    INC 1930
      SUM = 0.0                                                        INC 1940
      SUX = 0.0                                                        INC 1950
      SUY = 0.0                                                        INC 1960
      SUZ = 0.0                                                        INC 1970
      DO 226 I=1,NMASS                                                 INC 1980
      XI(I) = XI(I)-XS                                                 INC 1990
      ZI(I) = -ZI(I)+ZS                                                INC 2000
      AMK = AMI(I)*2.0                                                 INC 2010
      SUX = SUX+AMK*XI(I)*XI(I)                                        INC 2020
      SUY = SUY+AMK*YI(I)*YI(I)                                        INC 2030
      SUZ = SUZ+AMK*ZI(I)*ZI(I)                                        INC 2040
  226 SUM = SUM+AMK*XI(I)*ZI(I)                                        INC 2050
      AIXX = SUY+SUZ                                                   INC 2060
      AIYY = SUX+SUZ                                                   INC 2070
      AIZZ = SUX+SUY                                                   INC 2080
      AIXZ = SUM                                                       INC 2090
      GO TO 212                                                        INC 2100
  230 GO TO 10                                                         INC 2110
                                                                       INC 2120
C     XX AND YY TABLES                                                 INC 2130
300   CONTINUE                                                         INC 2140
      NSTA(1) = TEMP(1)                                                INC 2150
      NSTA(2) = TEMP(2)                                                INC 2160
      NSTA(3) = TEMP(3)                                                INC 2170
      NSTA(4) = TEMP(4)                                                INC 2180
      XLTOT=TEMP(5)                                                    INC 2190
      GOTO 10                                                          INC 2200
                                                                       INC 2210
C     SIDEWALL (INCLUDING APPENDAGES)                                  INC 2220
400   CONTINUE                                                         INC 2230
      GOTO (401,402),IOPT                                              INC 2240
401   YSW=TEMP(1)                                                      INC 2250
      XLSW=TEMP(2)                                                     INC 2260
      CFSW=TEMP(3)                                                     INC 2270
      CDSW=TEMP(4)                                                     INC 2280
      AVBMSW=TEMP(5)                                                   INC 2290
      READ (10) ZZZ                                                    INC 2300
      REWIND 10                                                        INC 2310
      GOTO 10                                                          INC 2320
C    BLOCK 4 OPTION 2 REMOVED.        NO APENDAGES                     INC 2330
  402 CONTINUE                                                         INC 2340
      GOTO 10                                                          INC 2350
                                                                       INC 2360
C     STERNSEAL                                                        INC 2370
500   CONTINUE                                                         INC 2380
      XSSI=TEMP(1)                                                     INC 2390
      ZSSI=TEMP(2)                                                     INC 2400
```

```
      ALEAK=TEMP(3)                                                    INC 2410
      CFSS=TEMP(4)                                                     INC 2420
      ELMAXS = TEMP(5)                                                 INC 2430
      DPSS=TEMP(6)                                                     INC 2440
      XLF=TEMP(7)                                                      INC 2450
      ARGA = ELMAXS/XLF                                                INC 2460
      COSTH = ARGA                                                     INC 2470
      THSSI = ARCOS(ARGA)                                              INC 2480
      SINTH = SIN(THSSI)                                               INC 2490
      GO TO 10                                                         INC 2500
                                                                       INC 2510
C     BOWSEAL                                                          INC 2520
 600  GO TO(610,620),IOPT                                              INC 2530
 610  CONTINUE                                                         INC 2540
      XBSI=TEMP(1)                                                     INC 2550
      CFBS=TEMP(2)                                                     INC 2560
      DPBS=TEMP(3)                                                     INC 2570
      ZBSI=TEMP(4)                                                     INC 2580
      ELMAXB = TEMP(5)                                                 INC 2590
      XBF=TEMP(6)                                                      INC 2600
      BLEAK=TEMP(7)                                                    INC 2610
      GOTO 10                                                          INC 2620
 620  CENCAB=TEMP(1)                                                   INC 2630
      GO TO 10                                                         INC 2640
                                                                       INC 2650
C     PLENUM                                                           INC 2660
700   CONTINUE                                                         INC 2670
      GO TO (705,710),IOPT                                             INC 2680
 705  CONTINUE                                                         INC 2690
      XLBW=TEMP(1)                                                     INC 2700
      XBBW=TEMP(2)                                                     INC 2710
      XPWV=TEMP(3)                                                     INC 2720
      WIDTH=TEMP(4)                                                    INC 2730
      XL=TEMP(5)                                                       INC 2740
      XCPO=TEMP(6)                                                     INC 2750
      BUBHGT=TEMP(7)                                                   INC 2760
      XLXPWV=XLBW-XPWV                                                 INC 2770
      PWVHT=(XPWV*XPWV-XLXPWV*XLXPWV)*.5/XL                            INC 2780
      XPWVXS=XPWV-XS                                                   INC 2790
      ABW=XBBW*XLBW                                                    INC 2800
      AB=WIDTH*XL                                                      INC 2810
      VCLNOM=(ABW+AB)*BUBHGT/2.                                        INC 2820
      GOTO 10                                                          INC 2830
 710  CONTINUE                                                         INC 2840
      FNCRIT=TEMP(1)                                                   INC 2850
      GO TO 10                                                         INC 2860
                                                                       INC 2870
C     PROPULSION                                                       INC 2880
```

```
800   CONTINUE                                                          INC 2890
      GO TO (805,810),IOPT                                              INC 2900
 805  CONTINUE                                                          INC 2910
      XPO=TEMP(1)                                                       INC 2920
      YPO=TEMP(2)                                                       INC 2930
      ZPO=TEMP(3)                                                       INC 2940
      GO TO 10                                                          INC 2950
C BLOCK 8 OPTION 2 REMOVED. ENGINE OUT INPUT IN BLOCK 16                INC 2960
  810 CONTINUE                                                          INC 2970
      GOTO 10                                                           INC 2980
                                                                        INC 2990
C     RUDDER                                                            INC 3000
900   CONTINUE                                                          INC 3010
      GO TO (905,910,915),IOPT                                          INC 3020
  905 XRO = TEMP(1)                                                     INC 3030
      YR=TEMP(2)                                                        INC 3040
      ZRO = TEMP(3)                                                     INC 3050
      RSPAN=TEMP(4)                                                     INC 3060
      RASPR=TEMP(5)                                                     INC 3070
      RAREA=TEMP(6)                                                     INC 3080
      RCLB=2.*PI*RASPR/(RASPR+3.)                                       INC 3090
      RTC=TEMP(7)                                                       INC 3100
      GO TO 10                                                          INC 3110
C     910 NOT USED                                                      INC 3120
  910 CONTINUE                                                          INC 3130
      GO TO 10                                                          INC 3140
 915  CONTINUE                                                          INC 3150
      GOTO 10                                                           INC 3160
                                                                        INC 3170
C     AERODYNAMICS                                                      INC 3180
1000  CONTINUE                                                          INC 3190
      XLAERO=TEMP(1)                                                    INC 3200
      BEAM=TEMP(2)                                                      INC 3210
      RHOA=.5*RHOINF*XLAERO*BEAM                                        INC 3220
      GOTO 10                                                           INC 3230
                                                                        INC 3240
C     WAVES                                                             INC 3250
1100  CONTINUE                                                          INC 3260
      IWAVSW=IOPT                                                       INC 3270
      IF(IWAVSW.GT.4) GO TO 70                                          INC 3280
      NWAVE=TEMP(1)                                                     INC 3290
      IF(NWAVE .EQ. 0) GOTO 10                                          INC 3300
      IF(NWAVE .GT. 10) GOTO 70                                         INC 3310
      BETAD=TEMP(2)                                                     INC 3320
      BETA=BETAD/RAD                                                    INC 3330
      COSBET=COS(BETA)                                                  INC 3340
      SINBET=SIN(BETA)                                                  INC 3350
      TC = 1.0                                                          INC 3360
```

```
      GO TO (1104,1106,1108,1108),IWAVSW                                INC 3370
1104  DO 1105 I=1,NWAVE                                                 INC 3380
1105  READ(5,1190) OMEGA(I),AW(I)                                       INC 3390
      GOTO 10                                                           INC 3400
1106  DO 1107 I=1,NWAVE                                                 INC 3410
1107  READ (5,1190) WAVLEN(I) ,AW(I)                                    INC 3420
      GOTO 10                                                           INC 3430
 1108 SHTWV=TEMP(3)                                                     INC 3440
      G1G=32.17                                                         INC 3450
      G2=G1G*G1G                                                        INC 3460
      G4=G2*G2                                                          INC 3470
      GOTO(10,10,1110,1111),IWAVSW                                      INC 3480
 1110 CONTINUE                                                          INC 3490
      PERL=TEMP(4)                                                      INC 3500
      PERH=TEMP(5)                                                      INC 3510
      WWN=(2.0*3.141592)*(1.0/PERH)                                     INC 3520
      WWX=(2.0*3.141592)*(1.0/PERL)                                     INC 3530
      GO TO 1112                                                        INC 3540
 1111 CONTINUE                                                          INC 3550
      WWN = TEMP(4)                                                     INC 3560
      WWX = TEMP(5)                                                     INC 3570
 1112 CONTINUE                                                          INC 3580
      UUU=SQRT(SHTWV/0.0185)*1.6878                                     INC 3590
      UU4=UUU**4.                                                       INC 3600
      CCC=(WWX/WWN)**(1./NWAVE)                                         INC 3610
      WWPO =WWN                                                         INC 3620
      DO 1113 I = 1,NWAVE                                               INC 3630
      WWPN = WWPO*CCC                                                   INC 3640
      WW =(WWPN+WWPO)/2                                                 INC 3650
      DDW = WWPN-WWPO                                                   INC 3660
      WWPO  = WWPN                                                      INC 3670
      WW4= WW**4.0                                                      INC 3680
      WW5 = WW**5.0                                                     INC 3690
      SS = 0.0081*G2/(EXP(0.74*G4/(WW4*UU4))*WW5)                       INC 3700
      OMEGA(I) =WW                                                      INC 3710
      AW(I) = SQRT(2.*SS*DDW)                                           INC 3720
 1113 CONTINUE                                                          INC 3730
      GO TO 10                                                          INC 3740
                                                                        INC 3750
C     INITIAL CONDITIONS                                                INC 3760
1200  CONTINUE                                                          INC 3770
      UO = TEMP(1)                                                      INC 3780
      THETO = TEMP(2)                                                   INC 3790
      DSO = TEMP(3)                                                     INC 3800
      DELPI=TEMP(4)                                                     INC 3810
      DPHI = TEMP(5)                                                    INC 3820
      GO TO 10                                                          INC 3830
                                                                        INC 3840
```

```
1300  CONTINUE                                                                  INC 3850
C     INPUT COMPLETED. 1) PRINT ALL INPUT                                       INC 3860
      WRITE(6,2004) TITLC                                                       INC 3870
      WRITE (6,2001) STIME,FTIME,DELO,TPRINO,DELPNT                             INC 3880
      WRITE (6,2002) IACCEL,IVEL,ITRAJ,ISIDWL,IBOWSL,ISTNSL,IWAVES,IRUD,        INC 3890
     1 IPROP,IAEROD,IRHS                                                        INC 3900
      WRITE(6,2021) I3DOF,ISRGE,ITRIM,IDIA                                      INC 3910
      WRITE (6,2003) NEQS, (TOL(J),J=1,NEQS)                                    INC 3920
      WRITE (6,219) WEIGHT,XS,ZS,AIXX,AIYY,AIZZ,AIXZ                            INC 3930
      WRITE(6,217)A,AIMAX                                                       INC 3940
      WRITE (6,2018) NSTA                                                       INC 3950
      WRITE (6,490) YSW,XLSW,CFSW,CDSW,VANGLE,VSPAN,VCHORD,VXO,VY,VZO,          INC 3960
     1 AVBMSW,VTC                                                               INC 3970
      WRITE (6,491) NAL,DAL,SAL,NDS,DDS,SDS,NTH,DTH,STH,NBB,DBB,SBB             INC 3980
      IF (IMM.GT.0)  WRITE(6,1549)   (XMO(J),J=1,IMNX)                          INC 3990
      WRITE (6,1519) IMM,IMNX,IMNY,IBMFIL,BTIME,IMT                             INC 4000
      IF (IMM.GT.0)  WRITE(6,1559) (YMI(J),J=1,IMNY)                            INC 4010
      WRITE (6,2010) XLBW,XBBW                                                  INC 4020
      WRITE (6,2011) XL,WIDTH,XCPO,VOLNOM,BUBHGT                                INC 4030
      WRITE (6,2020) DELPI                                                      INC 4040
      WRITE(6,2009) FNCRIT,XLTOT                                                INC 4050
      WRITE (6,2028) ENBFAN,BRPM,ENMFAN,EMRPM,ENSFAN,SRPM                       INC 4060
      WRITE (6,2013) XRO,YR,ZRO,RONO,RMAXO,RRATO,RREVO,DLRDO                    INC 4070
     1  ,RSPAN,RASPR,RAREA,RCLB,RTC                                            INC 4080
      WRITE (6,2012)        XPO,YPO,ZPO                                         INC 4090
      WRITE (6,2027) XLAERO,BEAM                                                INC 4100
      WRITE (6,2026) XBSI,CFBS,DPBS,ELMAXB                                      INC 4110
      WRITE (6,2025) XSSI,ZSSI,ALEAK,CFSS,ELMAXS,DPSS,XLF                       INC 4120
      WRITE (6,2017) UO,THETO,DSO                                               INC 4130
                                                                                INC 4140
C                    AND 2) INITIALIZE VARIABLES FOR CALCS.                     INC 4150
      DO 1302 I=1,40                                                            INC 4160
 1302 VAL(I) = 0.0                                                              INC 4170
      U = UO*1.6889                                                             INC 4180
      XSS=-(XS-XSSI)                                                            INC 4190
      ZSS=ZS-ZSSI                                                               INC 4200
      THETA = THETO/RAD                                                         INC 4210
      PHI = DPHI/RAD                                                            INC 4220
      THEQL=THETA                                                               INC 4230
      DS = DSO/12.                                                              INC 4240
      Z=-ZS+DS                                                                  INC 4250
      ZEQUIL=Z                                                                  INC 4260
      PHIMAX=0.                                                                 INC 4270
      TROLL=0.                                                                  INC 4280
      IRDS=0                                                                    INC 4290
      TL=0.0                                                                    INC 4300
C     WAVE PARAMETERS TABLE                                                     INC 4310
      IF(NWAVE .EQ.0) GOTO 1321                                                 INC 4320
```

```
      AMPTC=1.30287                                                          INC 4330
      GOTO(1310,1315),IWAVSW                                                 INC 4340
1310  DO 1311 I=1,NWAVE                                                      INC 4350
1311  WAVLEN(I)=2.*PI*G/(OMEGA(I)*OMEGA(I))                                  INC 4360
      GOTO 1317                                                              INC 4370
1315  DO 1316 I=1,NWAVE                                                      INC 4380
1316  OMEGA(I)=SQRT(2.*PI*G/WAVLEN(I))                                       INC 4390
1317  CONTINUE                                                               INC 4400
                                                                             INC 4410
C     CALCULATE INITIAL FREQUENCIES OF ENCOUNTER                             INC 4420
      DO 1318 I=1,NWAVE                                                      INC 4430
      WAVSLP(I) = 360.0*AW(I)/WAVLEN(I)                                      INC 4440
      OMEGAE(I) =2.*PI*(SQRT(G*WAVLEN(I)/(2.*PI))-U*COSBET)/WAVLEN(I)        INC 4450
      ENCPER(I) = 2.0*PI/OMEGAE(I)                                           INC 4460
1318  CONTINUE                                                               INC 4470
      WRITE (6,1191) NWAVE,BETAD,(OMEGA(I),OMEGAE(I),WAVLEN(I),AW(I),        INC 4480
     1               WAVSLP(I),ENCPER(I),I=1,NWAVE)                          INC 4490
      GOTO 1322                                                              INC 4500
 1321 WRITE (6,1192)                                                         INC 4510
1322  CONTINUE                                                               INC 4520
      DO 1303 I=1,4                                                          INC 4530
      DO 1303 N=1,11                                                         INC 4540
 1303 ETA(I,N) = 0.0                                                         INC 4550
      DVOLW = 0.0                                                            INC 4560
      FXWAV = 0.0                                                            INC 4570
      FYWAV = 0.0                                                            INC 4580
      FZWAV = 0.0                                                            INC 4590
      FKWAV = 0.0                                                            INC 4600
      FMWAV = 0.0                                                            INC 4610
      FNWAV = 0.0                                                            INC 4620
      ZBAR=Z                                                                 INC 4630
      PHIBAR=PHI                                                             INC 4640
      THEBAR=THETA                                                           INC 4650
      TIME=STIME                                                             INC 4660
      DELT = DELO                                                            INC 4670
      TPRINT=TPRINO-DELPNT                                                   INC 4680
      PWVCON=4.*WEIGHT/(RHO*G*XLBW)                                          INC 4690
      FNCON=SQRT(XLBW*G)                                                     INC 4700
      VX=VXO-XS                                                              INC 4710
      VZ = ZS-VZO                                                            INC 4720
      XP=XPO-XS                                                              INC 4730
      XR = XRO-XS                                                            INC 4740
      YP=YPO                                                                 INC 4750
      ZP=ZS-ZPO                                                              INC 4760
      ZR = ZS-ZRO                                                            INC 4770
      IF (IMM.EQ. 0) GO TO 1305                                              INC 4780
      DO 1304 J=1,IMNX                                                       INC 4790
 1304 XMI(J) = XMO(J) - XS                                                   INC 4800
```

```
 1305 CONTINUE                                                          INC 4810
      XCP = XCPO-XS                                                     INC 4820
      ZCP = ZS-BUBHGT                                                   INC 4830
      XBS=XBSI-XS                                                       INC 4840
      N=NSTA(3)                                                         INC 4850
      ZBS=ZS-ZBSI                                                       INC 4860
      DO 1364 J=1,N                                                     INC 4870
      DELYBS=XBBW/(N-1)                                                 INC 4880
       XX(3,J)=XBS-XSSI                                                 INC 4890
      YY(3,J)=-0.5*XBBW+(J-1)*DELYBS                                    INC 4900
 1364 CONTINUE                                                          INC 4910
      N=N-1                                                             INC 4920
      DO 1367 J=1,N                                                     INC 4930
      YAVGB(J)=(YY(3,J+1)+YY(3,J))/2.                                   INC 4940
 1367 CONTINUE                                                          INC 4950
      N=NSTA(4)                                                         INC 4960
      DELYSS=XBBW/(N-1)                                                 INC 4970
      DO 1365 J=1,N                                                     INC 4980
      XX(4,J)=-XS                                                       INC 4990
      YY(4,J)=-.5*XBBW+(J-1)*DELYSS                                     INC 5000
 1365 CONTINUE                                                          INC 5010
      N=N-1                                                             INC 5020
      DO 1368 J=1,N                                                     INC 5030
      YAVGS(J)=(YY(4,J+1)+YY(4,J))/2.                                   INC 5040
 1368 CONTINUE                                                          INC 5050
      XBOW=XLTOT-XS                                                     INC 5060
      N=NSTA(1)                                                         INC 5070
      DELX=XBSI/(N-1)                                                   INC 5080
      DO 1309 J=1,2                                                     INC 5090
      DO 1309 I=1,N                                                     INC 5100
      XX(J,I)=(I-1)*DELX-XS                                             INC 5110
 1309 YY(J,I)= YSW*(2*J-3)                                              INC 5120
      WRITE(6,1366) ((XX(J,N),N=1,11),(YY(J,N),N=1,11),J=1,4)           INC 5130
 1366 FORMAT (//17H XX AND YY ARRAYS /14H PORT SIDEWALL /2(11F10.2/),   INC 5140
     1 15H STBD. SIDEWALL /2(11F10.2/),9H BOW SEAL /2(11F10.2/),        INC 5150
     2 11H STERN SEAL /2(11F10.2/))                                     INC 5160
      N=NSTA(1)-1                                                       INC 5170
      DO 1308 I=1,N                                                     INC 5180
 1308 XAVG(I)=DELX*(2*I-1)/2.-XS                                        INC 5190
      CALL WAVES(TIME)                                                  INC 5200
                                                                        INC 5210
C     INITIALIZE BUBBLE PRESSURE, ABSOLUTE (PSF)                        INC 5220
      PB=PINF+DELPI                                                     INC 5230
      PBBAR=DELPI                                                       INC 5240
      PBAR=DELPI                                                        INC 5250
      PSS=PB+DPSS                                                       INC 5260
      PBS=PB+DPBS                                                       INC 5270
      AB=ABW-(ABW-AB)*(ZS+Z/BUBHGT)                                     INC 5280
```

```
      CDBUB=.37/((U/FNCON)**1.5655981)                                  INC 5290
      WATSLP=PWVCON*CDBUB/AB                                            INC 5300
      IF (IDIA.EQ.1) GO TO 6                                            INC 5310
      VOL=VOLNOM-.5*(AB+ABW)*(Z+ZS)-DVOLW                               INC 5320
     1+PWVHT*PWVCON*CDBUB                                               INC 5330
      GO TO 7                                                           INC 5340
 6    VOL=VOLNOM-.5*(AB+ABW)*(Z+ZS)-DVOLW+PBAR*.3175333                 INC 5350
 7    CONTINUE                                                          INC 5360
      BMASS=(PB/PINF)**(1./GAM)*VOL*RHOINF                              INC 5370
      WRITE (6,2023)                                                    INC 5380
      RETURN                                                            INC 5390
                                                                        INC 5400
C     RUN TERMINATOR                                                    INC 5410
 1400 WRITE(6,98)                                                       INC 5420
      STOP                                                              INC 5430
                                                                        INC 5440
C     BENDING MOMENT                                                    INC 5450
 1500 GO TO (1510,1520,1530,1540), IOPT                                 INC 5460
 1510 IMM = TEMP(1)                                                     INC 5470
      IF (IMM.GT.3)  GO TO 70                                           INC 5480
      IMNX = TEMP(2)                                                    INC 5490
      IF (IMNX.GT.10)  GO TO 70                                         INC 5500
      IMNY = TEMP(3)                                                    INC 5510
      IF (IMNY.GT.7)  GO TO 70                                          INC 5520
      IBMFIL = TEMP(4)                                                  INC 5530
      BTIME = TEMP(5)                                                   INC 5540
      IF (IMM.EQ.3)  IMT = TEMP(6)                                      INC 5550
      GO TO 10                                                          INC 5560
 1520 DO 1521 J=1,7                                                     INC 5570
 1521 XMO(J) = TEMP(J)                                                  INC 5580
      IF (IMNX.LE.7)  GO TO 10                                          INC 5590
      READ 1522, (XMO(J),J=8,IMNX)                                      INC 5600
      GO TO 10                                                          INC 5610
 1530 DO 1531 J=1,IMNY                                                  INC 5620
 1531 YMI(J) = TEMP(J)                                                  INC 5630
      GO TO 10                                                          INC 5640
 1540 CONTINUE                                                          INC 5650
      GO TO 10                                                          INC 5660
                                                                        INC 5670
1600  CONTINUE                                                          INC 5680
      GO TO(1605,1610,1615),IOPT                                        INC 5690
 1605 CONTINUE                                                          INC 5700
C  VALUES INPUT FOR STBD SCREW                                          INC 5710
      THST1=TEMP(1)                                                     INC 5720
      NPS=TEMP(2)                                                       INC 5730
      STHS=TEMP(3)                                                      INC 5740
      IF(NPS.EQ.0.0) GO TO 1609                                         INC 5750
      READ(5,1950)(TIS(J),J=1,NPS)                                      INC 5760
```

```
      READ(5,1950)(THSTS(J),J=1,NPS)                                    INC 5770
      GO TO 10                                                          INC 5780
 1609 THSTS(1)=THST1                                                    INC 5790
 1610 CONTINUE                                                          INC 5800
C  VALUES INPUT FOR PORT SCREW                                          INC 5810
      THST2=TEMP(1)                                                     INC 5820
      NPP=TEMP(2)                                                       INC 5830
      STHP=TEMP(3)                                                      INC 5840
      IF(NPP.EQ.0.0) GO TO 1614                                         INC 5850
      READ(5,1950)(TIP(J),J=1,NPP)                                      INC 5860
      READ(5,1950)(THSTP(J),J=1,NPP)                                    INC 5870
      GO TO 10                                                          INC 5880
 1614 THSTP(1)=THST2                                                    INC 5890
 1615 CONTINUE                                                          INC 5900
C  VALUES INPUT FOR RUDDER                                              INC 5910
      DELR=TEMP(1)                                                      INC 5920
      NPR=TEMP(2)                                                       INC 5930
      IF(NPR.EQ.0.0) GO TO 1616                                         INC 5940
      READ(5,1950)(TIR(J),J=1,NPR)                                      INC 5950
      READ(5,1950)(DELRUD(J),J=1,NPR)                                   INC 5960
      GO TO 10                                                          INC 5970
 1616 DELRUD(1)=DELR                                                    INC 5980
      GO TO 10                                                          INC 5990
                                                                        INC 6000
 1700 GO TO (1705,1710),IOPT                                            INC 6010
 1705 NB=TEMP(1)                                                        INC 6020
      READ(5,1950)(TMEB(I),I=1,NB)                                      INC 6030
      READ(5,1950)(DELB(I),I=1,NB)                                      INC 6040
      GO TO 10                                                          INC 6050
 1710 NS=TEMP(1)                                                        INC 6060
      READ(5,1950)(TMES(I),I=1,NS)                                      INC 6070
      READ(5,1950)(DETS(I),I=1,NS)                                      INC 6080
      GOTO 10                                                           INC 6090
                                                                        INC 6100
C     TITLE CARD (ALL 80 COLUMNS )                                      INC 6110
 1800 READ  (5,2022)  TITLC                                             INC 6120
      GO TO 10                                                          INC 6130
                                                                        INC 6140
C     FAN MAPS                                                          INC 6150
1900  CONTINUE                                                          INC 6160
      GO TO (1905,1910,1915),IOPT                                       INC 6170
1905  CONTINUE                                                          INC 6180
      ENBFAN=TEMP(1)                                                    INC 6190
      BRPM=TEMP(2)                                                      INC 6200
      NPTSB=TEMP(3)                                                     INC 6210
      READIN=TEMP(4)                                                    INC 6220
      IF (READIN .EQ. 0.0) GO TO 10                                     INC 6230
      READ (5,1950) (PBFAN(J),J=1,NPTSB)                                INC 6240
```

```
      READ (5,1950) (Q8FAN(J),J=1,NPTSB)                                INC 6250
      GO TO 10                                                          INC 6260
1910  CONTINUE                                                          INC 6270
      ENMFAN=TEMP(1)                                                    INC 6280
      EMRPM=TEMP(2)                                                     INC 6290
      NPTSM=TEMP(3)                                                     INC 6300
      READIN=TEMP(4)                                                    INC 6310
      IF (READIN .EQ. 0.0) GO TO 10                                     INC 6320
      READ (5,1950) (PMFAN(J),J=1,NPTSM)                                INC 6330
      READ (5,1950) (QMFAN(J),J=1,NPTSM)                                INC 6340
      GO TO 10                                                          INC 6350
1915  CONTINUE                                                          INC 6360
      ENSFAN=TEMP(1)                                                    INC 6370
      SRPM=TEMP(2)                                                      INC 6380
      NPTSS=TEMP(3)                                                     INC 6390
      READIN=TEMP(4)                                                    INC 6400
      IF (READIN .EQ. 0.0) GO TO 10                                     INC 6410
      READ (5,1950) (PSFAN(J),J=1,NPTSS)                                INC 6420
      READ (5,1950) (QSFAN(J),J=1,NPTSS)                                INC 6430
      GO TO 10                                                          INC 6440
1950  FORMAT(8F10.0)                                                    INC 6450
C     ERROR IN INPUT                                                    INC 6460
   70 CONTINUE                                                          INC 6470
      WRITE (6,79) ISYS                                                 INC 6480
      STOP                                                              INC 6490
  79  FORMAT(34H INPUT ERROR - - - STOP - -  ISYS= ,I3)                 INC 6500
  98  FORMAT(1H1,20(/),50X,19H COMPLETED ALL RUNS )                     INC 6510
99    FORMAT(I3,I2,7F10.0)                                              INC 6520
 191  FORMAT (16I5)                                                     INC 6530
 192  FORMAT (5F10.0)                                                   INC 6540
 195  FORMAT(///10X,65HERROR IN INPUT --- DELT AND/OR DELPNT EQUALS ZEROINC 6550
     1 --- JOB ABORTED )                                                INC 6560
 175  FORMAT (2I2/(8F10.0))                                             INC 6570
 216  FORMAT(///10X,82HERROR IN INPUT --- INPUT INERTIA ELEMENTS LEAD TOINC 6580
     1 ZERO DETERMINANT --- JOB ABORTED )                               INC 6590
 217  FORMAT(22H INERTIA MATRIX, AIMAX  6E15.4/(22X,6E15.4))            INC 6600
 219  FORMAT(30H WEIGHT, C.G., INERTIA MOMENTS 7F12.3)                   INC 6610
 305  FORMAT ( 11F7.0 )                                                 INC 6620
 490  FORMAT(15H SIDEWALL INPUT 12(F8.3,1X))                            INC 6630
 491  FORMAT(26H SIDEWALL TABLE PARAMETERS 4(I4,F7.3,F7.3))             INC 6640
1190  FORMAT(2F10.0)                                                    INC 6650
 1191 FORMAT(/12HONO OF WAVES I2,10H BETA(DEG)F5.0/15H OMEGA(RAD/SEC) , INC 6660
     15X,16H OMEGAE(RAD/SEC) 5X,16H WAVE LENGTH(FT) 5X,14H AMPLITUDE(FT)INC 6670
     - 5X,16HMAX  SLOPE (DEG)5X,13HPERIOD,E(SEC)/(F8.4,12X,F8.4,4F20.3))INC 6680
 1192 FORMAT(/11HOCALM WATER)                                           INC 6690
 1519 FORMAT(32HOMOMENT CALC. CONTROL PARAMETERS 4I5, F8.3, I5 )        INC 6700
 1522 FORMAT ( 5X,7F10.0)                                               INC 6710
 1549 FORMAT(22H MOMENT CALCS. AT X OF 11F10.3)                         INC 6720
```

```
1559 FORMAT(22H MOMENT CALCS. AT Y OF 11F10.3)                                  INC 6730
2004 FORMAT(33H1SES MOTIONS AND LOADS PROGRAM - 20A4,/)                         INC 6740
2001 FORMAT(23H START AND FINISH TIMES 2F10.2/                                  INC 6750
    -22H INITIAL TIME INTERVAL F12.4/                                           INC 6760
    -18H START PRINTING AT F8.2,17H IN INCREMENTS OF F8.2)                      INC 6770
2002 FORMAT(24H INTERMEDIATE PRINT TAGS 16I5)                                   INC 6780
2003 FORMAT(39H NO. OF STATE EQUATIONS, AND TOLERANCESI5/(10X,10E12.2))INC 6790
2009 FORMAT(23HOCRITICAL FROUDE NUMBER F15.4,5X,19H TOTAL CRAFT LENGTH INC 6800
    1       F15.4)                                                              INC 6810
2010 FORMAT(34HOPLENUM, LENGTH AND WIDTH AT WATER 2F12.4)                       INC 6820
2011 FORMAT(34H PLENUM, LENGTH AND WIDTH AT HULL  2F12.4/                       INC 6830
    -       35H PLENUM, CENTER OF PRESSURE AT HULL F12.4/                       INC 6840
    -23H PLENUM, NOMINAL VOLUME F12.1,10X, 6HHEIGHT F12.4)                      INC 6850
2012 FORMAT(/33H PROPULSION, X, Y, Z COORDINATES  3F12.4/)                      INC 6860
2013 FORMAT(/28HORUDDER, X, Y, Z COORDINATES  3F12.4/                           INC 6870
    -        41H RUDDER, ON, MAX, RATE, REVERSE, INITIAL  5F12.4/               INC 6880
    -        33H RUDDER,SPAN,ASPECT,AREA,CLB,T/C  5F12.4)                       INC 6890
2017 FORMAT(/39HOINITIAL CONDITIONS, VELOCITY (KNOTS) = F7.2, 5X,               INC 6900
    -        13HPITCH (DEG) = F8.3,5X,12HDRAFT (IN) = F8.2)                     INC 6910
2018 FORMAT( 49H NUMBER OF STATIONS, SIDEWALLS (P+S), SEALS (B+S) ,4I5)INC 6920
2020 FORMAT( 38H PLENUM, INITIAL PRESSURE, GAGE (PSF)  F8.2)                    INC 6930
2021 FORMAT(79H PROGRAM OPTION SWITCH SETTINGS (LATERAL PLANE,CONSTANT INC 6940
    -SPEED,TRIM,MEMBRANE)     4I5)                                              INC 6950
2022 FORMAT (20A4 )                                                             INC 6960
2023 FORMAT ( 1H1 )                                                             INC 6970
2025 FORMAT( 16H STERNSEAL INPUT  7F12.4 )                                      INC 6980
2026 FORMAT( 16H BOWSEAL INPUT    7F12.4 )                                      INC 6990
2027 FORMAT( 19HOAERODYNAMICS INPUT  7F12.4)                                    INC 7000
2028 FORMAT( 33HOFANS, NO. + RPM, BOW,MAIN,STERN  3(F10.0,F10.1))               INC 7010
     END                                                                        INC 7020
```

BIBLIOGRAPHY

1. Robert L. Trillo, Marine Hovercraft Technology, Leonard Hill, 1971.

2. Oceanics Incorporated, Report No. 71-84, August 1971, Technical Industrial Park, Plainview, N.Y. 11803.

3. Leo, D.G. and Boncal, R., XR-3 Surface Effects Ships Test Craft: A Mathematical Model and Simulation Program with Verification, Master's Thesis, Naval Postgraduate School, Monterey, 1973.

4. Mayer, R.D., Fan Laws Simplify Performance Calculations, Power, p. 77-80, August 1946.

5. Forbes, G.T., Validation of the Six Degree of Freedom Mathematical Model of the XR-3 in Calm Water, Master's Thesis, Naval Postgraduate School, Monterey, 1974.

6. Wener, N.L. and Burke, F.P., Surface Effect Ship Research with XR-1 Testcraft, AIAA Paper 74-313 presented at the AIAA/SNAME Advanced Marine Vehicles Conference, San Diego, Californai, February 25-27, 1974.

INITIAL DISTRIBUTION LIST

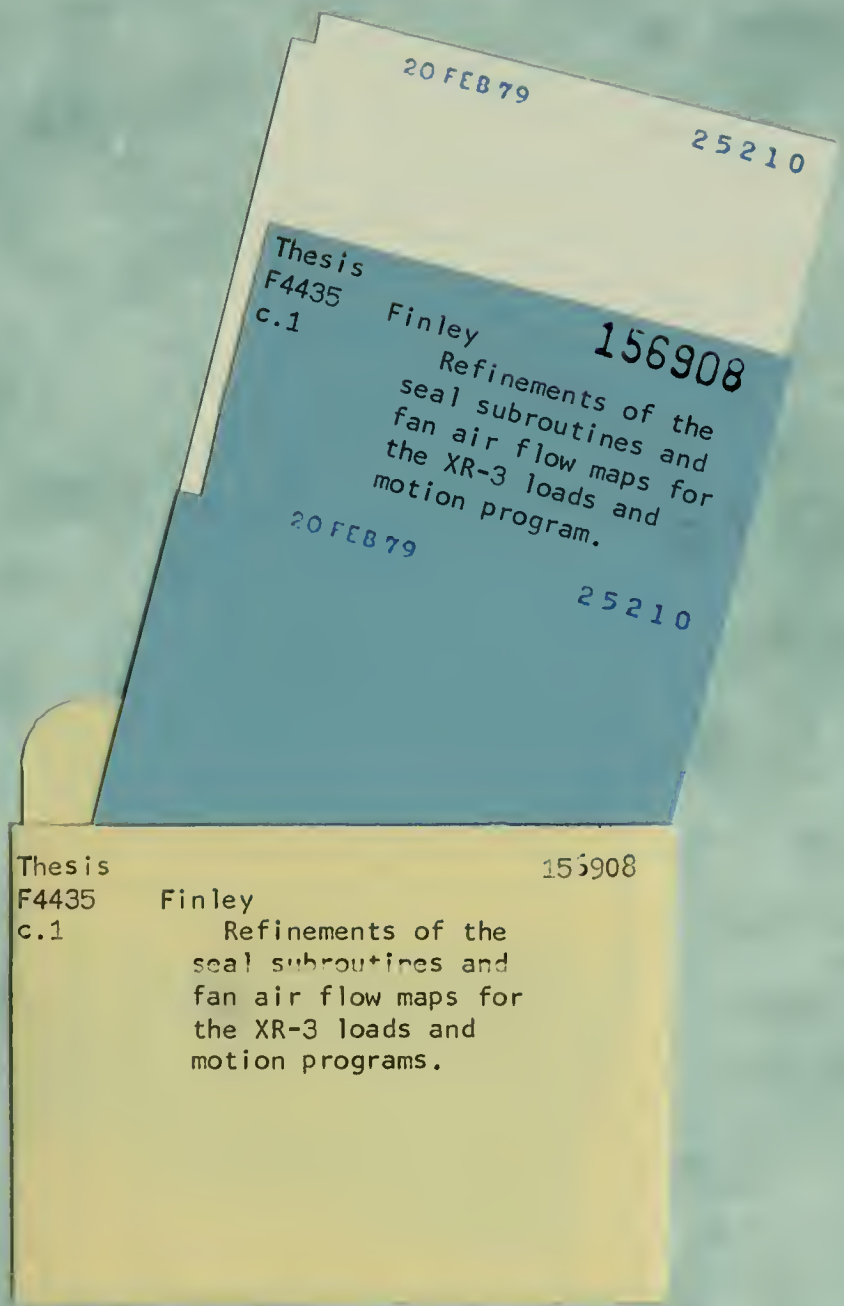
		No. Copies
1.	Defense Documentation Center Cameron Station Alexandria, Virginia 22314	2
2.	Library, Code 0212 Naval Postgraduate School Monterey, California 93940	2
3.	Assoc. Professor Alex Gerba, Jr., Code 52GZ Department of Electrical Engineering Naval Postgraduate School Monterey, California 93940	5
4.	Professor George J. Thaler, Code 52TR Department of Electrical Engineering Naval Postgraduate School Monterey, California 93940	1
5.	Assoc. Professor Donald M. Layton, Code 57LN Department of Aeronautical Engineering Naval Postgraduate School Monterey, California 93940	1
6.	CDR Donald Hay, USN Surface Effect Ships Project Office, Navy Dept. P.O. Box 34401 Bethesda, Maryland 20034	1
7.	Mr. Sydney Davis, Code PMS-304-31A Department of the Navy Surface Effect Ships Project Office P.O. Box 34401 Bethesda, Maryland 20034	1
8.	Mr. James E. Blalock, Code 1607 Department of the Navy Naval Ship Research and Development Center Carderock Laboratory Bethesda, Maryland 20034	1
9.	Mr. Arnold W. Anderson, Code PMS-304-31A.1 Department of the Navy Surface Effect Ships Project Office, PM-17 Bethesda, Maryland 20034 (P.O. Box 34401)	1

10. LCDR Robert A. Finley — 2
USS W. V. PRATT (DLG-13)
FPO, New York, New York 09501

11. LCDR Michael N. Hayes, NAVSEC 6110.10 — 1
Naval Ship Engineering Center
Center Building, Prince Georges Center
Hyattsville, Maryland 20782

12. Mr. Reilly Conrad, Code 6136 — 1
Naval Ship Engineering Center
Center Building, Prince Georges Center
Hyattsville, Maryland 20782

13. Mr. Al Ford, Code 163 — 1
Department of the Navy
Naval Ship Research and Development Center
Carderock Laboratory
Bethesda, Maryland 20034


20 FEB 79
25210
Thesis
F4435
c.1
Finley
156908
Refinements of the seal subroutines and fan air flow maps for the XR-3 loads and motion program.
20 FEB 79
25210
Thesis
F4435
c.1
Finley
156908
Refinements of the seal subroutines and fan air flow maps for the XR-3 loads and motion programs.

thesF4435
Refinements of the seal subroutines and
3 2768 001 00369 2
DUDLEY KNOX LIBRARY